1955 X

STOCKHOLM

THESIS

ACTA RADIOLOGICA
SUPPLEMENTUM 120

LANE MEDICAL LIBRARY
JUL 6 1955

PRACTICAL PHOTOGRAPHIC PROBLEMS IN RADIOGRAPHY

WITH SPECIAL REFERENCE TO HIGH-VOLTAGE TECHNIQUE

By

OVE MATTSSON

LANE MEDICAL LIBRARY
STANFORD UNIVERSITY
300 PASTEUR DRIVE
PALO ALTO, CALIF.

Diss. med.
Stockholm. Karolinska Institutet
30 MRS 1955

STOCKHOLM 1955

This volume which forms
Supplement 120 to Acta Radiologica may be obtained from
ACTA RADIOLOGICA, Stockholm 2, Sweden,
or the usual agents.

FROM THE ROENTGEN DIAGNOSTIC DEPARTMENT
(DIRECTOR: PROFESSOR KNUT LINDBLOM), KAROLINSKA SJUKHUSET,
STOCKHOLM, SWEDEN

PRACTICAL PHOTOGRAPHIC PROBLEMS IN RADIOGRAPHY

WITH SPECIAL REFERENCE TO HIGH-VOLTAGE TECHNIQUE

By

OVE MATTSSON

The knowledge of our tools, their possibilities and limitations is essential in our work.

STOCKHOLM 1955
KUNGL. BOKTRYCKERIET P. A. NORSTEDT & SÖNER

Translation:

LARS G. LINDQVIST

GRETA SARGEANT

The photographic illustrations and the drawings were made by the author. Preliminary reports on some parts of the present work were presented at meetings of the Swedish Association of Medical Radiology on Dec. 13, 1952, Sept. 25, 1954 and Dec. 5, 1954.

To MY WIFE

Digitized by the Internet Archive
in 2026

https://archive.org/details/IA40153502_0012

CONTENTS

	Page
Preface	7
Introduction	9
High-voltage technique — a general survey	11
Some historical aspects	11
The gain in photographic effect	13
New focus dimensions	14
Special applications of fine-focus tubes	16
Some physical problems	18
The changed character of the radiograph	20
Conclusions	22
Photographic effect and dose as products of radiation	23
Roentgen apparatus	23
The photographic procedure	24
Experimental arrangements	25
Technique of dose measurements	27
The exposure required for unit film density	28
The radiation dose from different aspects	31
The effect of additional tube filtration	37
Conclusions	41
The change in contrast of different substances with variation in the voltage	42
Introduction	42
Experimental technique	42
The contrast media and the test chambers	43
Exposure, processing and measuring of the films	44
Results of the investigation	45
Conclusions	52
Recording of contrast as a photographic problem	53
The density curve and the importance of gamma value	53
The influence of different voltages	55
General aspects of development	57
Ways of obtaining uniform development with high contrast	60
Influence of temperature	63
Conclusions	64
Intensifying screens. Problems and developments	66
A historical review of the screen problems	66
A new type of screen	71
A new support	76
Metal screens	78
Conclusions	79

Page

CROSS-GRIDS, GRID MOTION AND VISIBLE PATTERN 81
Some fundamental concepts 81
The history and progress of secondary screening with special regard to the cross-grid principle 85
The problem of motion in cross-grids 95
Formulation of the problem 95
Some introductory photographic tests 95
Distribution of illumination — a geometrical analysis 97
Applications to conventional grids 101
Suitable motion of arbitrary grids 104
Application to unorthodox grid systems 105
Some practical problems 107
Effect of deviation from the correct angle of motion 108
Technical aspects of movement 108
Loss of definition with a superimposed grid pattern 114
Moving cross-grids in practical use 118
Stroboscopic effects: Visible grid pattern in the film caused by intermittence of the tube current 125
Intermittence of the current supply 125
Explanation of stroboscopy with grids 126
Selected references 127
Possibilities of stroboscopic pattern formation in the film — an analysis 128
Size of the grid movement 135
Grid drive mechanisms — a review of applied principles 136
A graphical study of the motion of different grid mechanisms 138
Conclusions. An 'ideal' construction 143

SOME FACTORS WHICH INFLUENCE THE QUALITY OF THE RADIOGRAPHIC IMAGE 147
The off-focus radiation 147
Introduction 147
A survey of the literature 149
Studies of certain modern tubes 152
Ordinary primary diaphragms and the off-focus radiation 161
The close-to-focus principle 162
Experiments on the practical size of off-focus radiation 167
Practical aspects 169
Conclusions 171
The backscatter phenomenon 172
Some introductory tests 172
Methods of reducing backscatter 175
An antiscattering foil 176
The backscatter in cassettes 178
A related secondary radiation effect 180

A PHANTOM FOR THE STUDY OF THE RADIOGRAPHIC RECORDING OF VESSELS CONTAINING CONTRAST MEDIA 183
The need of a special test object. Some references 183
A method for the production of vessel phantoms 184
Practical applications of the vessel-like test objects 189

SUMMARY 195
REFERENCES 198

PREFACE

It was my chief, Professor Knut Lindblom, who suggested the task of analysing certain problems connected with the use of higher kilovoltages in radiography, especially as regards the angiographic technique. It is thanks to Professor Lindblom's help and encouragement that I have been able to complete the study.

The staff of the Roentgen Department of Karolinska Sjukhuset and the Institute of Radiophysics of the King Gustav V Jubilee Clinic (Director: Professor Rolf Sievert), where the investigations were carried out, have facilitated my work by practical assistance, and have helped me in many respects.

Mr. Bo Lindell, Civilingenjör, has given me much valuable advice on problems of a radiophysical nature. In the practical execution of many experiments, and measurements, performed in Dr. Robert Thoraeus' section of the Institute, Mr. Valter Andersson and Mr. Arne Nilsson have assisted me in an excellent manner.

Mr. Arne Lundh, Civilingenjör, sensitometry specialist and chief of the control section of the Swedish State Photochemical Industries, Ceaverken, has helped me to have all photographic test material developed in a scientifically correct manner, and has instructed me in the use of the densitometer of his department, which was placed at my disposal. His invaluable help and advice have facilitated my work. The photographic material used in the measurements was supplied by the same company.

A series of measurements were performed with a microdensitometer belonging to the department of Physical Cell Research (Directors: Professor Torbjörn Caspersson and Professor Arne Engström), and Mr. Lennart Aquilonius gave me much valuable help.

A phantom designed by Professor Dr. Herbert Schober, Borstel, Germany, was placed at my disposal.

Mr. Sven Ledin, Tekn. Dr., Mr. Karl Fenz, Dr. Ing., and their assistants in the Georg Schönander Ltd., Stockholm, have devoted much time to the production of several grid constructions and experimental apparatus based on my calculations. Mr. Georg Schönander has shown great personal interest in my work.

Philips Ltd. of Holland and England and their Swedish subsidiary, Svenska Aktiebolaget Philips, have supplied much technical information and also provided me with experimental apparatus.

The Swedish firm Elema has also supplied me with apparatus for experiments.

Mr. Gunnar Embring, Apothecary of Pharmacia, Upsala, has given a great deal of information and has supplied preparations for the experiments.

Mr. Lars Lindqvist, Fil. mag., Librarian of ASEA, Västerås, has devoted much energy to the English translation. Mrs. Greta Sargeant also took part in this work. Their skill and interest were inestimable.

Dr. John Roth, Sunbury on Thames, has spent much time in going over the manuscript.

Miss Karin Dahl, editorial secretary, Acta Radiologica, has given me valuable advice in editing the manuscript.

Miss Ingrid Ekborn has performed an important part of the clerical work.

Generous support from the 'Syskonen Wesséns Stiftelse' enabled me to conclude my task.

To all those mentioned above and to many others, I am deeply indepted.

Stockholm, January 1955

Ove Mattsson

INTRODUCTION

The accelerated use of high kilovoltages for radiography has been accompanied by a series of problems. Some are new and others, well-known from previous techniques, have grown more important through the changed qualities of the radiation. The use of higher voltages signifies an important progress, and an analysis of vital problems should be of great interest, especially in view of angiographic technique.

I have selected some problems, which in my opinion are of definite interest, and a review of the studies made will be presented.

A brief retrospective survey of the development of the high-voltage technique will be given and its peculiarities will be illustrated by a series of my own investigations, concerning photographic effect and dosage as well as the effect of different tube filtrations at various levels of voltage up to 180 kV. A study of the variations in contrast of some substances of importance in modern radiographic technique will be presented.

Problems of contrast connected with the photographic procedure will be discussed and a study of intensifying screens, especially the newest type using barium lead sulphate as a fluorescent material, will be reported.

Secondary radiation, which is of increasing importance as a factor disturbing the picture quality at higher voltages, has necessitated the use of highly efficient secondary diaphragms. Double-layer grids with crossed elements have come more and more into use. Normally the cross-grids have been stationary, and the grid pattern has been visible in the radiograph. In my opinion this is by no means satisfactory, particularly in the study of blood vessels. Against the background of the development of secondary diaphragms, especially of the crossed type, I will present a detailed analysis of the principles of motion of crossed systems for obtaining radiographs free from any grid shadows. The stroboscopic phenomena which also result in irregular illumination of the picture will be dealt with. I presume these problems to be of real interest at the actual moment, when high definition is more and more pursued. The striking reduction in definition produced by the presence of a grid pattern will be demonstrated.

The importance of off-focus radiation to the radiograph will be discussed and a simple way of reducing its undesirable effects with ordinary radiographic tubes will be described. Backscatter phenomena, also a fac-

tor producing undesirable scatter on the film, will be touched upon, and preventive measures especially suited for the high-voltage technique will be suggested.

The evaluation of different radiographic techniques is often most easily done with phantoms. There has been a demand for phantoms that will reproduce the conditions during angiographic examinations. A method of producing phantoms with channels of very fine diameter simulating vessels will be described. These may be filled with different contrast media. Such phantoms have been used in a comparative microdensitometric study of the actual concentration of the media in smaller vessels in angiography, on which I shall report. This study has been made possible by the radiographs free from grid pattern, obtained by the principles mentioned.

My work is to be conceived as an analysis of certain practical problems of high-voltage technique, which refer to the quality of the photographic recording, especially the problem of contrast, together with studies of possible ways of improving the radiographic results.

HIGH-VOLTAGE TECHNIQUE — A GENERAL SURVEY

Some historical aspects

The progress in the field of roentgen diagnostics has gone continuously towards the use of higher voltages. This may be explained by the fact that high-voltage technique involves certain important advantages. It is proposed to present a survey of its progress.

A characteristic feature of a harder radiation which was apparent from the very beginning was its greater penetrating power and higher radiographic effect. As long as the older unstable gas tube without a hot cathode was used, the tube current could only be regulated by means of the voltage at a given internal gas pressure, and there was no free choice of voltage. The hot-cathode tubes which were introduced by W. D. Coolidge in about 1913 opened the field for the variation of voltage and amperage independently of one another. The quality and quantity of the radiation could thus be controlled at will and the development of these tubes revolutionized radiology. The fact that the tube performance with constant electrical factors was stable, was a particularly great advantage; settings could be repeated day after day with confidence.

Among those who first used high voltages and realized their value were E. Weber (1924), M. Gortan (1924) and F. Zacher (1925), who used voltages up to 100 kV. This voltage level may be considered as the borderline value between conventional and high-voltage technique from modern point of view. Gortan reported good results of exposures of 0.1 seconds of the digestive tract. At that time, however, there was a wide difference of opinion as regards the practical use of the new voltage ranges. H. Chantraine (1925), for example, emphasized the superiority of soft radiation in the examination of the lungs.

The pioneer, as regards high voltages of the magnitude which we are beginning to use today, was no doubt J. Stephani, who in 1929, showed excellent results in lung roentgenography up to 150 kV. His work seems

to have fallen into oblivion later and for a long time the highest voltages used were at a much lower level.

In 1931, T. Rövekamp commented on a so-called 'hard ray method', and discussed its possibilities. His opinion was that high tube voltage is really suitable only for the examination of the chest, particularly the lungs. The method should also be of value in examination of the heart which is visualized with good sharpness owing to the short exposure possible. According to Rövekamp other parts of the body would scarcely enter into question. It should be noticed that no voltages over 95 kV were mentioned. Rövekamp's comments on high voltage technique for radiographic purposes in general were not very enthusiastic, which may largely be explained by the fact that at that time no satisfactory control over secondary radiation existed. Primary diaphragming on one hand, and the grid systems on the other, must have left a great deal to be desired, as seen against subsequent developments. I wish to emphasize the increasing importance of secondary radiation at higher kilovoltages, which is wellknown by all radiologists. The general fogging produced by scattered radiation will easily become very disturbing and will cause a reduction of the contrast. These circumstances, which are highly important to roentgen diagnostics in general, have been discussed by many authors. The problem finds a clear expression in W. Bronkhorst's well-known studies of, among other subjects, contrast in roentgenography (1927). The constant decrease in efficiency of secondary diaphragms at raised voltages has been demonstrated early by several authors of whom K. Lindblom (1934), and W. Rump (1938), may be mentioned. Later S. Ledin (1952), A. Nemet, W. F. Cox, T. H. Hills (1953), and others, have made detailed comparisons of various types of grids as related to voltage.

For detailed information on the development of secondary diaphragms — a very interesting problem in this connection — references may be made to the review given in the chapter on grid developments in the present work (page 85). The increasing demands on secondary diaphragms have called for a higher degree of efficiency in these diaphragms. The distinctly growing interest in cross-member grid systems and their increasing use is explained by the fact that they give a more uniform filtration of secondary radiation from different directions and good efficiency without making exceptionally high grid bars necessary. The comparisons made by the three last-mentioned authors — Nemet, Cox, Hills — between different types of grids are of interest in this connection. These comparisons speak strongly in favour of cross-grids. On the basis of numerous measurements and phantom tests made to illustrate the inherent possibilities of the high-voltage technique E. Buchheim (1952), F. Wachsmann, K. Breuer and E. Buchheim (1952),

and others, have used cross-grids at the highest voltages and demonstrated their superiority.

With the progress made in eliminating secondary radiation, it has been possible to use higher tube voltages with increasing advantage. The capacities of roentgen apparatus have also improved successively, and voltages of 125 kV and above are increasingly used. Naturally, the more efficient secondary diaphragms cause a certain reduction of the actual yield of radiation, but in return the higher voltage gives such an increase of exposure intensity that exposures of a shortness not previously imagined are now possible.

The gain in photographic effect

The relation between the exposure required and the voltage — a question of fundamental importance, which has been one object of the present investigation — has been discussed by several authors. It may be expressed by the formula:

$$E = mAs \times kV^n \times k$$

where E is the exposure intensity producing a certain film density and k a constant. Thus the exposure intensity is proportional to the n:th power of the kilovoltage where a standard density is desired.

Weber, in 1924, stated that the third or fourth power of the voltage could normally be estimated to be proportional to the radiographic intensity. Later, E. Weber and O. Brezina (1926) indicated the fourth power as suitable for heavier radiographic objects. G. W. Files (1926), from investigations with apparatus of that time, found that the radiographic density obtained varies directly with the square of the voltage, all other factors remaining constant. Files, however, omitted the use of screens, which explains the divergence of the values.

The problems have further been discussed by P. Profitlich (1930) and by E. Weber and C. Russo (1931). In the majority of papers, values of n of about 4 are given. The last-mentioned authors emphasized the great importance of object thickness and filtration for this value. Variations between the second and sixth powers were thus observed for various objects. The tests involved voltages up to 100 kV. None of the authors mentioned discussed the value of n for higher voltages.

The absence of an unequivocal mathematical expression for the relation quoted was pointed out in 1941 by G. J. v. d. Plaats, D. v. Dijk and Coolsma. Later on, v. Dijk (1951) used the fifth power in connection with formulas for optimum results in radiography. According to A. Bierman and W. H. Boldingk (1951), the value of n is not

constant in the interval 50 to 100 kV, but the average appears to be 4.8. These authors recommended the value 5 for practical use, but emphasized that the reciprocity law failure in the photographic material may cause certain errors in practical work. This effect, which is noticeable only with visible light from screens, means that extremely short or long durations of exposure have a relatively lower degree of efficiency with a change in the value of n as a consequence. The value 5 for the power would mean that a rise from 80 to 100 kV would produce approximately a triplication of the exposure intensity. Since there are no data of this kind for the range above 100 kV, this problem has been included in the present investigation. Graphs composed by Buchheim (1952) for voltages up to 150 kV give some idea of the exposure required for a certain blackening. However, since these graphs are based on very few and sparse measurements, they give no guidance for a mathematical formulation of the relation. The trend towards a reduced yield from the rise of voltage is, however, evident.

It is obvious that the markedly increased effect of radiation at higher voltages is of vital importance. Short exposure times with reduced blurring due to movement even in the examination of objects of quite large dimensions, facilities for making rapidly repeated exposures, and, not least, reduced doses of radiation for the patient are some of the most important advantages. Several of these facts were discussed by K. C. Clark (1953), who showed that approximately only one-tenth of the radiation dose will be required at 130 kV as compared with 80 kV for an equivalent exposure. The high-voltage technique in connection with obstetrics and diseases of the chest was discussed by F. H. Kemp (1954). He emphasized the marked reduction of dose and pointed out that high-voltage is very satisfactory for roentgen pelvimetry. The problem of doses at higher voltages has been the object of special investigation and will be dealt with elsewhere in this work.

New focus dimensions

Along with the reduced current imposed on the tube for a certain effect came the possibilities of reducing the size of the focus. Whereas previously focus diameters of about 2 mm had been necessary for the majority of advanced examinations, the diameter could now be reduced to approximately 1 mm. Naturally this caused an improvement in definition. The next step was the introduction of tubes with a focus about 0.3 mm in diameter. Although these tubes permitted loads which were merely a fraction of those of earlier tubes, these loads were sufficient with the high voltage. In return, they allowed procedures which pre-

viously had not been practicable, such as direct enlargement of the radiographic image by a large increase of the object and film distance. In this way, the amount of secondary radiation from the object onto the film was also reduced, as was pointed out at an early stage by F. Groedel (1925) and H. Laurell (1931). It was not necessary to use any secondary diaphragm and so the required amount of radiation was further reduced. Owing to the small size of the focus, the penumbral unsharpness, in spite of the enlarging, would remain at, or even below, the threshold value for resolution of the intensifying screens and a good radiographic result would therefore be obtained.

It should be mentioned that A. Vallebona introduced a method of direct enlarging of the radiographic image. He discussed (1931) the application in front of a tube of a disc with a small hole transmitting a very narrow beam of radiation. This pin-hole functioned as a very small focus, and an enlarged image could be produced directly by a suitable location of film and object. In this connection he also outlined a technique for tomography with a rotary movement.

The fine-focus enlarging technique, which, in its present form, is fairly new, has been discussed by a number of authors. In 1951, E. A. Zimmer demonstrated the results of direct image enlargement with a 0.3 mm target in the examination of the skull and pointed out that this represented significant progress. Zimmer confirmed the need of high voltages, but for his own part he used voltages which did not even reach 100 kV. The apparatus then available does not seem to have been suited for high voltages. An interesting general review of the enlarging technique and its principles was presented by v. d. Plaats in 1952. E. H. Wood (1953) considered the method to be of great clinical value, especially since the enlarged radiographic image could give information impossible to obtain from conventional films. Wood recommended the procedure particularly for the study of lesions of the skeletal system. Its usefulness for various purposes, such as skull angiography, was demonstrated by G. Heuser and W. Lemcke (1953), while D. Schoen (1953) emphasized the advantages of the method for the study of the larynx. In a study of the enlargement technique in the radiology of the ear, nose and throat, E. Samuel (1953) showed some very beautiful radiographs of the temporal bone. As regards examinations with barium contrast media, J. Bücker (1952) maintained that, with high-voltage technique and fine-focus tubes, it is easier to obtain good films of the mucosal folds of the stomach. According to Bücker, one reason for this is that lower compression is required and the ray penetration at the voltages used — 125 kV — is higher.

A. Frantzell has shown interest in the theoretical problems concerning sharpness for different degrees of enlargement. In a study

presented in 1954, he emphasized the comparatively slight increase in real definition obtainable with the 0.3 mm focus and enlargement. A smaller focus should give better results. The importance of the screen properties was pointed out. In a comparison between enlargement radiography and conventional technique, H. Büchner (1954), pleads the superiority of the latter for the proper rendering of small details.

It might be discussed whether for conventional routine diagnostic work, with the exception of special purposes, the enlarging technique will give any essential contribution to the diagnostical resources as compared with a first-class conventional technique. In fact, opinions differ on this point. A frequent experience is that a sufficiently short exposure cannot often be used to the desired extent. As will be emphasized later, the voltage should not be raised too much for examinations of the skeleton. These facts may be the reason why the technique has been accepted fairly slowly. However, it should be stressed that the possibility of using fine foci is in any case an epoch-making progress. The method is not to be regarded as a substitute for the conventional technique in general, but as a complement to other routine work.

It is possible that the predominating applications of the 0.3 mm focus tube will be in certain special fields but that in these fields a very marked expansion of diagnostic resources may be expected.

Special applications of fine-focus tubes

There remains a strong impression that the enlarging technique practised up to now is not the primary task of the fine-focus tube. In fact, in special fields of application, for instance tomography and stereoradiography, a great deal is to be expected from these tubes. As an example may be mentioned the *tomograph* with rotary movement and a small angle of movement designed by Lindblom (1954). Judging from the results so far obtained, it is a very valuable development. The tube, as well as the cassette, rotates during the exposure at a speed of 100 to 300 R. P. M. According to Lindblom, this construction has been more successful than others in dissolving the summation images and producing a good rendering of the layers. The distance technique makes grids unnecessary.

A. Beck (1952) also reported good results from direct enlargement with tomography, using a more conventional technique with linear travel of the tube. V. Backlund (1954) reported good results obtained with a tomograph using a distance technique and also a multiple-plane cassette for simultaneous tomography of several sections of the object in accordance with the principle developed by B. G. Ziedses des Plantes (1933), M. de Abreau (1948) and W. Watson (1953). Backlund uses

the fine-focus for shorter distances, but also utilizes larger sizes of focus when required. This arrangement exposes the patient to particularly small doses.

When *stereoscopic* examinations are concerned, high resolution of detail is of the greatest importance. The eye has an extremely high capacity of perceiving minute differences in the visual angle, and thereby generating an impression of difference in distance. According to H. Rein, and others, the minimum perceptible difference in distance is about 0.1 mm at 50 cm and 0.02 mm at 20 cm. These threshold values correspond to extremely low differences in visual angle and small change between the films in a stereoscopic pair. There is a considerable step between these values and the absolute resolution of radiographs obtained with the conventional technique. The stereoscopic radiograph will therefore only be an imitation of a three-dimensional rendering; the principal lines will be distinguishable, whereas the details, in which the eye is accustomed to distinguish delicate patterns, will be rendered incompletely. In reality the radiograph is deficient in these valuable patterns, at least when the conventional technique is used.

A great improvement has been achieved by the reduction in the size of the focus to one-third. Firstly, increased maximum definition is gained, which is particularly perceptible in the non-screen technique; secondly, the parts of the object situated farther away from the film will possess good sharpness. A large object will, therefore, as a whole, be more stereoscopically attractive. With a well-balanced technique, exquisite stereoradiographs may be produced, especially of the skeletal parts.

It would probably be better if screens could be abandoned in stereoradiography so that the narrow focus might be utilized fully. Strangely enough, no attention has been paid to the focus problem by the authors of the recent stereoradiographic literature, A. Hasselwander (1954), and others. This, I feel, is a problem of central importance. Nor have earlier authors in this field, M. Cohn and W. Barth (1931), and others, made any comments on this problem viewed from the angles mentioned.

As a result of the small foci an increased number of details will be present in the radiograph. In order to obtain a selection of the details of actual diagnostic value it is often desirable to employ a method of separating different layers. Tomography seems to increase in importance because of that. Radiographic stereoscopy may also be expected to be more utilized.

Although the reduction of the focus size is always of the greatest value, I am not convinced that the 0.3 mm focus is the optimum answer for all purposes. It would perhaps be more useful to follow the middle course by using, for example, a 0.6 mm focus and reach a higher per-

missible load. The result in any case would be a distinct improvement in resolution compared with conventional tubes and the advantages could be utilized with the more usual techniques. For ordinary routine work without enlargement, such a focus should be very suitable. The lower penumbral unsharpness of the smaller sized foci cannot be fully utilized because of the screens. The considerably higher permissible tube load is a factor of very great importance. With such a tube an increase in distance would give an effect corresponding to that of the true fine-focus tube.

Some physical problems

As regards the purely physical conditions which characterize the emission and absorption of radiation at higher voltages, most of the research performed has concerned therapeutical problems. In therapy voltages have been used up to a multiple of the values which lie in the range of conventional diagnostics. A very ample literature is available, but only a few selected works which present details of value from a diagnostic point of view will be reviewed in this survey.

J. G. Trump and R. W. Cloud (1940) demonstrated by means of graphs the increased penetration and depth dose at increased voltages and the change of the secondary radiation. These authors used voltages up to values much higher than any diagnostic or therapeutic apparatus ordinarily can produce. K. E. Corrigan (1940) compared, from the physical point of view, the radiation generated at different voltages used in therapy and showed, *inter alia*, how scattered radiation dominates in harder radiation, owing to the higher penetration.

L. F. Lamerton (1941) made a more detailed study of radiation at 140 kV, and C. W. Wilson (1945) discussed the quality and quantity of secondary radiation in media which are irradiated at high voltages. Ledin (1952) in his work on the physical background of contrast in roentgenograms with special regard to scattered radiation, presented informative graphs of the amount of and relation between the scattered and the primary radiation received by the film with different objects and varied technique. It is mainly the influence of the various types of grids which is discussed. Ledin used kilovoltages up to 140. H. Gajewsky (1954) carried out similar studies of the physical conditions up to 150 kV with different radiographic techniques.

Some essential problems associated with absorption will be briefly discussed. Because of the changed character of the radiation at higher kilovoltage, the differences in absorption between various substances are no longer so marked. The result is a reduction of film contrast which will be noticeable throughout the complete series of substances present

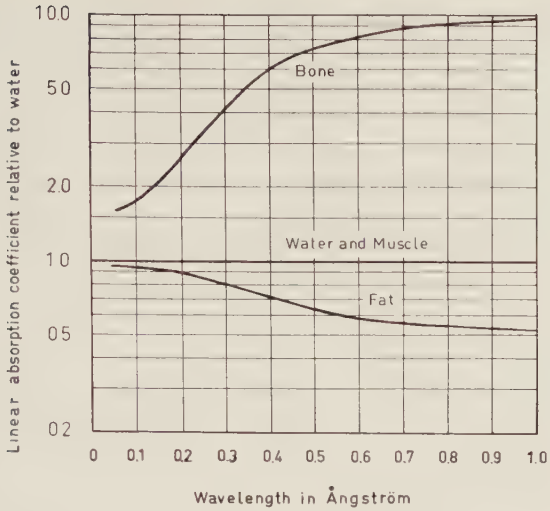


Fig. 1. Change in absorption of different tissues with the wavelength. Diagram redrawn from F. W. Spiers (1946).

in the body. This reduction of contrast is a disadvantage, particularly since at the higher kilovoltages it is in any case extremely difficult to limit the intense contrast-reducing effect of the secondary radiation.

The relation between some substances from the point of view of absorption is clearly demonstrated in Fig. 1 from F. W. Spiers (1946). It shows the change in absorption of some different tissues, with the wavelength. With shorter wavelengths the curves show a tendency towards conformity with the unit line represented by water. At extremely high energies, corresponding to more than 1,000 kV, complicated conditions occur through so-called 'pair formation'. As pointed out by O. Glasser, E. H. Quimby, L. S. Taylor and J. L. Weatherwax (1952) this particular effect as an absorption process is, at present, of little practical interest to the radiologist.

Applied to practical problems, the facts discussed mean that, for instance, the skeleton loses more and more of its radio-opaqueness as compared with the soft tissues. For this reason it is recommended, for example, not to exceed 110 kV in skeletal examinations. The conditions connected with the reduction of contrast at higher voltages have been discussed from various points of view by C. Wegelius (1953, 1954). In an experimental study of different grids E. Dale Trout and John P. Kelley (1954) stated that the only limit to the voltage that can be used in radiography is the limitation imposed by contrast. The limiting voltage is the one at which contrast has been reduced to the point where diagnosis becomes doubtful.

It is appropriate to stress the intimate relationship between contrast and definition, which has been suggested by CHANTRAINE (1933) and others. A higher degree of unsharpness requires higher contrast to make a certain object visible. By the reduction of penumbral unsharpness from 0.3 mm to 0.1 mm — the magnitude to be expected when changing from a tube with a conventional 1 mm focus to another of 0.3 mm focus — a loss in contrast of some 20 per cent is tolerable. CHANTRAINE, surprisingly enough, finds this value almost insignificant, and in his opinion the size of the focus is therefore of no great importance. This, however, applies to the conditions which prevailed at the time of the work in question. Today, when the demands are higher, it must be maintained that the opportunities of using small-sized foci are extremely important and increase the possibilities of obtaining good radiographic results, in spite of low image contrast. The most extensive employment of the high-voltage technique has been in conjunction with small foci.

The changed character of the radiograph

An obvious phenomenon observed in radiography at high voltages, associated with the reduced contrast, is that the various details of the object are represented in the image by a remarkably compressed scale of densities. With the conventional technique, details, such as skeletal and soft-tissue parts, can scarcely be depicted together owing to a too great difference in absorption. The representation of bones will easily be too thin and the soft tissues too dense. With the high-voltage technique, however, they may be combined in the image with a smaller difference in densities. This permits the coverage of a considerable range of object densities in one single exposure. This phenomenon is observed to an excessive extent at very high voltages, such as 1,000 kV, as demonstrated by W. J. TUDDENHAM, J. HALE and E. P. PENDERGRASS (1953), and others. A chest radiograph made with these radiation energies shows a remarkable levelling of the densities of different tissues, and one has a clear view of the mediastinum as well as the lung fields. All calciferous tissues, such as the ribs, as well as pathologic calcifications, practically disappear. On the other hand, these strongly levelled tissues in the film contrast very nicely against the regions containing air, such as the bronchial trees, and produce a peculiar and interesting representation of the chest. As was shown by WACHSMANN, BREUER and BUCHHEIM in 1952, the visibility of air-filled cavities in surrounding soft-tissue areas does not suffer very much at higher voltages. The investigations made by these authors, however, refer to much lower voltages than those of TUDDENHAM *et al.*

The apparent increase in visibility of the air-filled system against other tissues in the type of chest radiograph referred to above seems partly to be explained by the fact that, because of the levelling, no parts are outside the range of film densities and that soft tissue regions in themselves contain less details than if other techniques are used. CHANTRAINE (1933) points out the importance of superimposing details to visibility. An irregular background of a detail requires a multiplication of its size and contrast if visibility is to be reached. In this case the superimposed details have, to a very high extent, been reduced, so that the bronchial tree is clearly visible.

Although the voltages may be as high as practically possible, soft tissue will be well reproduced with relatively good contrast in comparison with air. This fact does not permit of the conclusion that the high-voltage technique should be well suited for soft-tissue studies. Although the compressed range of blackening sometimes gives a fairly good visualization of the soft-tissue contours of the object, this should not be taken as an indication that a perfect rendering of soft-tissue detail is obtained at the same time. There is a considerable reduction of contrast in the soft-tissue parts and fat, muscles, etc. show diminished differences. Low voltages are indispensable for work of this kind.

Any advantage of the soft parts of different densities being depicted in one exposure in the high-voltage technique may possibly be said to be imaginary in the case of chest radiography. It is an established practice in some clinics to make an additional heavily exposed film of the soft parts of the mediastinum. If very high voltages were used as a routine measure for the examination of the lungs, it might be expected that each examination would also have to be supplemented by a low-kilovoltage exposure to make calciferous tissues, such as pathologic calcifications, visible. WACHSMANN, BREUER and BUCHHEIM advise against voltages higher than 110 kV for calciferous tissues, including skeletal parts.

For contrast agents of the barium sulphate type, the reduction in absorption seems to be of less importance. This fact has been pointed out by the last-mentioned authors. LINDBLOM (1951) has also produced most excellent films of the stomach at 200 kV. BÜCKER (1952) stressed the importance of an increased penetration of radiation in contrast examinations with barium sulphate. According to this author, a much better film is obtained also when more dense layers of contrast are depicted, a fact which facilitates the technique. The use of finer foci also produces better films of the mucosal folds of the stomach. LEDIN (1952) has pointed out the gain in detail in the organs filled with barium sulphate when higher voltages are used. U. COCCHI (1954), having used voltages up to 125 kV, emphasized that the high-voltage technique is suitable

for most exposures of the digestive tract with contrast medium, but that there exist certain limitations in the case of the biliary and urinary tract.

Conclusions

The following characteristics of radiography with high voltages may be enumerated.

The higher energy of the radiation permits of a shorter exposure.

The patient is exposed to a lower dose of radiation.

A lower load is imposed on the anode of the tube, permitting a smaller focus with consequent increase in sharpness.

Secondary radiation is more disturbing and requires secondary diaphragms of more intricate construction, preferably cross-grids.

Because of the lower differentiation of tissue opacities, the contrasts will be very much reduced. The radiograph contains details visible in tissues of widely different density and thickness.

It appears from this, that the high-voltage technique embraces many great advantages. The most important of these are probably the short exposure times required and the possibilities of using fine foci. The low radiation dose gives opportunities for quick serial exposures and of studying rapid physiologic sequences.

The increased secondary radiation is controllable to a certain extent but the reduced contrast caused by the physical factors of absorption cannot be remedied. The only way is to afford the smaller contrasts a chance to appear with a minimum of interference from disturbing secondary radiation. Reduction of this secondary radiation is therefore particularly important. Increased sharpness, possible through fine foci, may compensate to some extent for the low contrast.

The chapters that follow will give contributions to further information regarding different problems in high-voltage technique.

PHOTOGRAPHIC EFFECT AND DOSE AS PRODUCTS OF RADIATION

To throw more light on some of the problems connected with high-voltage technique I have carried out a series of investigations. Although a great deal of similar research has earlier been made, which is evident from the literature, I believe that my work will give a clearer picture particularly concerning the region 100 to 200 kV. The studies to be presented in this chapter will show the influence of kilovoltage on various factors. The exposure required for a certain film density, and the dose obtained, as well as the effect produced by additional tube filtration, are the principal factors now to be considered.

Roentgen apparatus

The investigations now to be described here were carried out with a roentgen tube of therapy type (Metalix), which was the property of the Institute of Radiophysics and which was especially suited for measurements of various kinds. It had a stationary anode and was water-cooled. The total filtration of the tube window was approximately 1 mm Al (L. Lorentzon 1954). By a Greinacher circuit for constant-potential rectification this tube was supplied with a very constant continuous current. In comparison with the usual 4-valve or 6-valve systems, the current graphs of which may vary a great deal from one equipment to another, the type of current was decidedly more well-defined. Reference may be made to A. Bouwers (1929), who demonstrated the striking difference in current curves of different types of tubes for an ordinary alternating voltage, problems concerning the characteristic 'passage' of the tubes, etc. Such problems were also discussed by A. F. Neboschew (1952). It should also be pointed out that a constant-potential circuit will give a relatively better radiographic output than other systems with regularly varying potential and current. The radiation is continuously produced at the same voltage, and less effective radiation from rising and falling parts of the voltage graphs are eliminated. The shape of the graphs for voltage and current with different equipments was shown and discussed by E. A. W. Müller (1950). J. Meiler (1950) reported on the influence of these factors upon picture quality.

With this apparatus currents down to about 1.0 mA could be readjusted without difficulty, which facilitated the choice of suitable times of exposure. Special tests showed that there was no reason to suspect that the small values of amperage would give inadequate intensity of emission. In those cases where reciprocity law failures can occur, such as in using intensifying screens, no variation of the time was necessary. Instead, the intensity could be varied by means of the amperage and in certain cases by the regulation of distance.

The kilovoltage was measured with a static voltmeter, which was calibrated against an open spark gap between spheres.

The photographic procedure

A brief account will be given of the photographic technique used. With slight modification it has been employed in all photographic investigations reported in this work.

The intention in this case was not to test different makes of roentgen film: only one brand was used, and this material may be considered representative of the products now available in the market. Its sensitivity and contrast represent a fair average of the types of film available, and it has been used in parallel with other films in everyday practice for a fairly long time.

Ordinary roentgen film to be used with screens was employed, as well as non-screen film. The material was delivered direct from the factory, but was stored for a few weeks at room temperature. The same emulsion numbers were used for the whole series of tests. Separate test series were made for the selection of suitable times of exposure and amperage. These specimens were developed immediately and studied before the definite series were made. Single samples from these series were also picked and developed directly for control, whereas all films in the definite test series were processed at the same time. The development was carried out with great precision, for an exactly determined time and under thermostatically controlled temperature conditions with constant agitation. The time of development was 4 minutes at 20° C (68° F). The composition of the developer principally corresponded to Formula D 19 b recommended by the Eastman Kodak Co. for roentgenographic purposes. Its composition was as follows:

Metol	2.5 g
Sodium sulphite (cryst.)	70 g
Hydroquinone	9 g
Sodium carbonate (cryst.)	50 g
Potassium bromide	4 g
Water to make	1,000 g

The described processing technique was used to obtain maximum uniformity and exactness of results. Fixing, washing and drying were also performed under uniform conditions, drying was effected by circulating air at room temperature after treatment with a wetting agent.

The density values were read in a transmission densitometer of physical type with a photoelectric tube. It was manufactured by Baldwin, England, and was especially suited for roentgen film. The measurements were made with diffuse light. Special arrangements were made to maintain a constant operating voltage.

Experimental arrangements

The arrangement of the apparatus, the test objects and the film is shown in Fig. 2. The tube-to-film distance was as a rule 100 cm. For the tests with cassettes and screens a wax phantom, 16 cm in thickness, was used. It constituted an approximate equivalent to a soft tissue body of the size of the abdominal region of a patient in anterioposterior view with moderate compression. The field size was 400 cm^2.

The absorbent used for the tests with non-screen film was a 8 cm layer of water. It was estimated to give an approximate equivalent of the thicknesses of tissue that are usually depicted on such film, *e. g.* peripheral parts of limbs, etc. The field size was 80 cm^2. All measurements were made with the cassette or film at a distance of 5 cm from the absorbing body.

A simple method of producing water phantoms of desired dimensions was tried. A thin water-proof plastic envelope was filled with water and placed between two thin, but stiff cardbord sheets. The desired thickness of the layer was easily obtained.

In the experiments reported here, no secondary diaphragms were used. Since the investigations cover so wide a range on the kilovoltage scale, one particular secondary diaphragm can not possibly be the most suitable one for both low and for high kilovoltages. Separate types are required, and at present no grid may be said to fulfil the demands of, for instance, a 180 kV technique. In an informative survey like this one, it seems best to leave out the grid in order to ensure similar, always reproducible conditions for all measurements involved.

The principal matter is to show the *relative* change of different factors with variation in the voltage. The conditions prevailing with a certain grid might easily be calculated if a test were made with and without the grid. The effect of an arbitrary grid upon the exposure is proportionally of the same order within wide ranges of voltages, according to graphs prepared by A. Nemet, W. F. Cox and T. H. Hills (1953), E. D. Trout and J. P. Kelley (1954), and others.

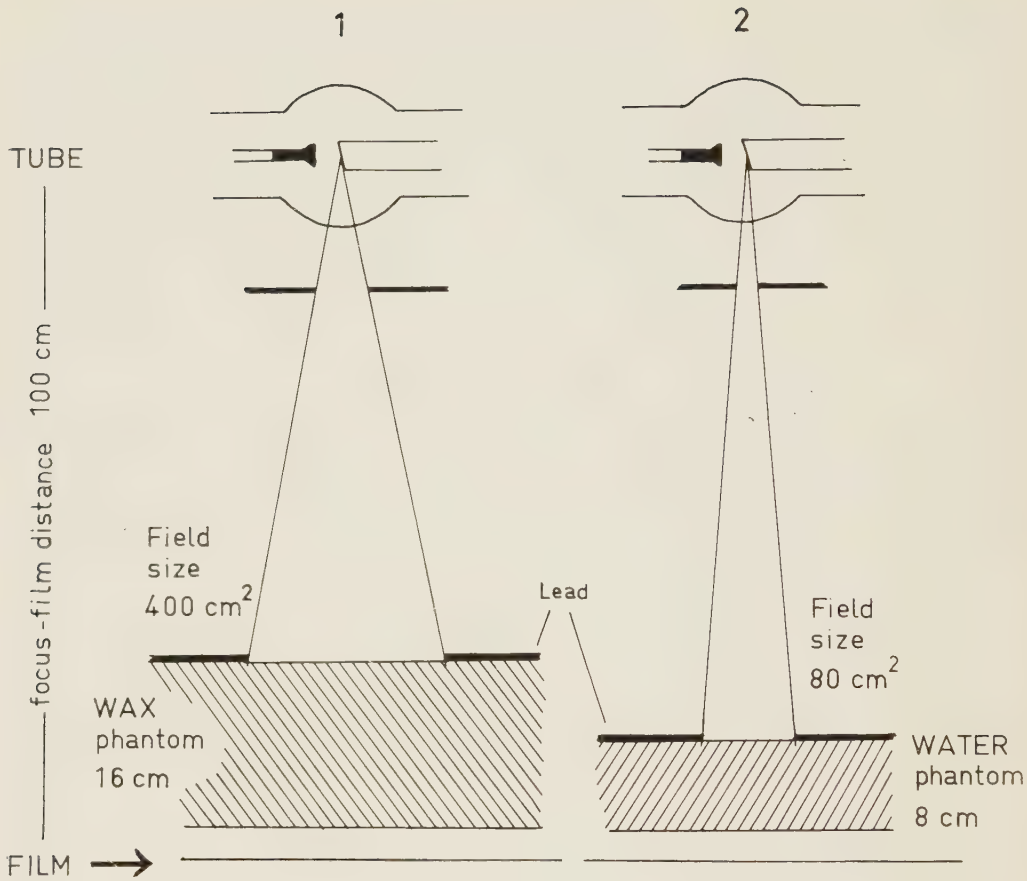


Fig. 2. Experimental arrangements used in the investigations. Case 1 refers to radiography of ordinary objects with a film-screen combination. Case 2 represents conditions with non-screen technique.

The tests with film in cassettes with intensifying screens were made with a standard screen of the type used in routine work for a variety of purposes, among them angiography. It was a screen of average sensitivity with a medium degree of definition. For this series of tests it may be considered to be representative of the large group of calcium tungstate screens. The same screen was used for the whole range of voltages. A comparison was also made with another type of screen containing a fluorescent substance of different type, barium lead sulphate. This screen and its properties will be discussed in detail in a special chapter. It was designed especially for higher voltages.

Technique of dose measurements

Since the question of radiation dose is of very great interest in diagnostic roentgenology, a series of dose measurements were made, partly in parallel with the photographic tests. The technique used for these tests will be briefly described.

A Philips universal roentgen dosimeter was used for the measurements. Its construction was discussed by J. Fransen and W. J. Oosterkamp in 1952. It is very simple to use: charging of the ionization chamber and reading were done in a matter of a few seconds. The same apparatus is used continuously at the 'Radiumhemmet' to estimate, for instance, doses in connection with rotation treatment. At first the ionization chamber used in the experiments was calibrated with a chamber of the Victoreen type, which should be very insensitive to changes in the quality of radiation. The capacity of the test chamber was about 0.2 r, while the Victoreen chamber (type V 3) had an uncomfortably low sensitivity

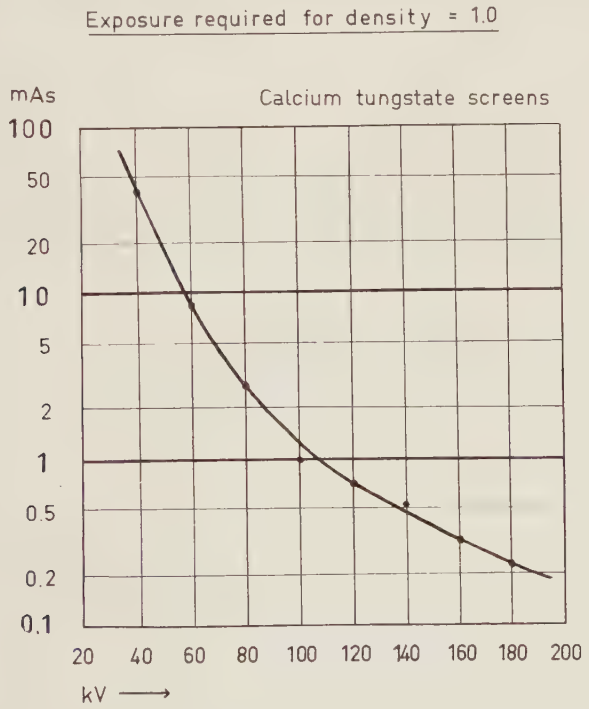


Fig. 3. The required mAs for unit film density with an ordinary screen-film combination with calcium tungstate screens (Film: Cea Vicor X. Screens: Patterson Par-Speed. 16 cm wax phantom.)

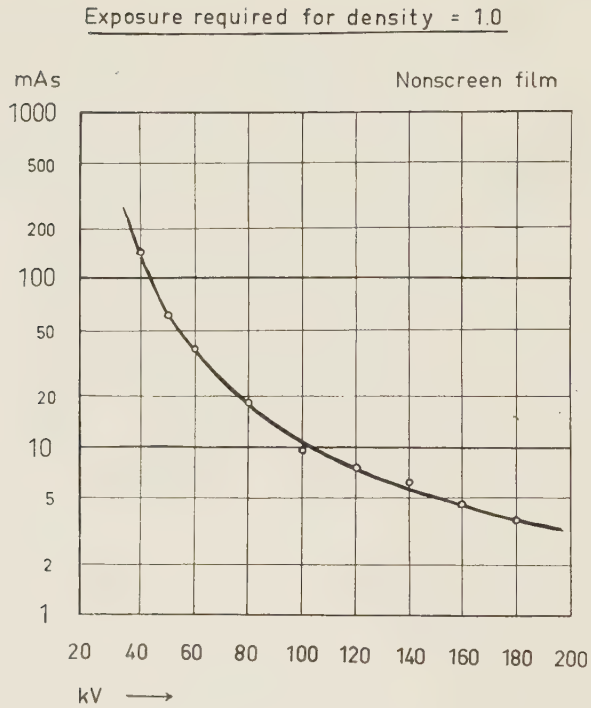


Fig. 4. The required mAs for unit density with a non-screen film. (Film: Cea Textur X. 8 cm water phantom.)

with a capacity amounting to some tens of roentgen units, although of course permitting of more exact measurements. The calibration was made at different voltages, and a calibration graph was plotted as a guide to the subsequent measurements.

The measurements were performed according to the usual routine of the Institute. The general principles of measurements of this kind have been discussed by O. Glasser, E. H. Quimby, L. S. Taylor and J. L. Weatherwax, and others. The dose values employed are ordinarily an average of five measurements.

The exposure required for unit film density

The factor of greatest importance in routine work is the *mAs*-value. It serves to give a guiding value for each exposure. The electrical readjustments are based upon it, and it provides a certain measure of the work of the tube.

The graph in Fig. 3 shows the mAs value required for a film density of 1.0 at different kilovoltages and for these experimental conditions when

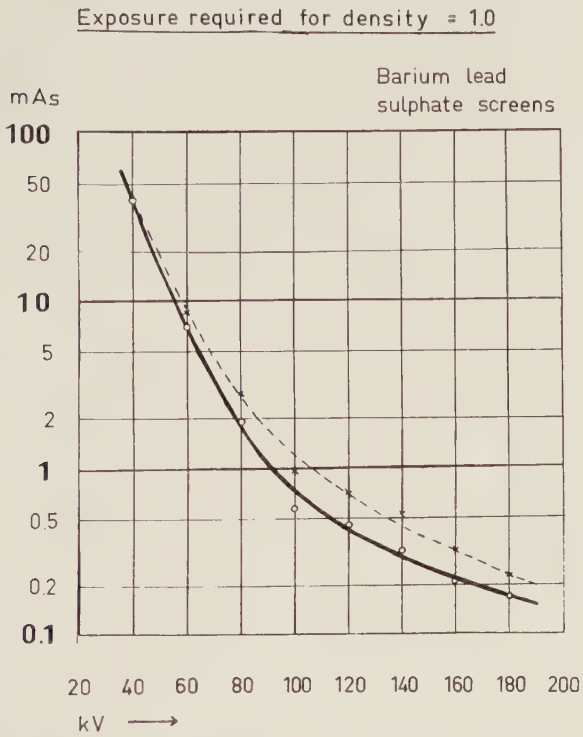


Fig. 5. The required mAs for unit film density with an ordinary roentgen film combined with barium lead sulphate screens ('high-voltage screens'). The dotted line which is introduced for comparison represents the values of the calcium tungstate screen. (Film: Cea Vicor X. Screens: Kodak Type 80. 16 cm wax phantom.)

calcium tungstate screens are used. It will be seen that the reduction of power consumption of the tube with a rise of the kilovoltage is very considerable. Relatively, however, the gain will be increasingly smaller with rising voltages. The values presented by E. Buchheim (1952) for similar material are of the same order of magnitude, although his measurements do not cover the same voltage range.

As has been mentioned previously, some authors have defined a proportionality between the photographic effect of radiation and a certain power of the voltage, which would serve as a guidance in the choice of exposure data in routine work. A formula has already been presented, in which n is the value of the power of the kilovoltage. (Cf. page 13.) It may be of interest to study the values of power which can be derived from the graph reproduced here. They are tabulated below:

Values of n for a typical screen-film combination:

40— 60 kV	4.3
80—100 kV	4.0
120—140 kV	2.7
160—180 kV	2.0

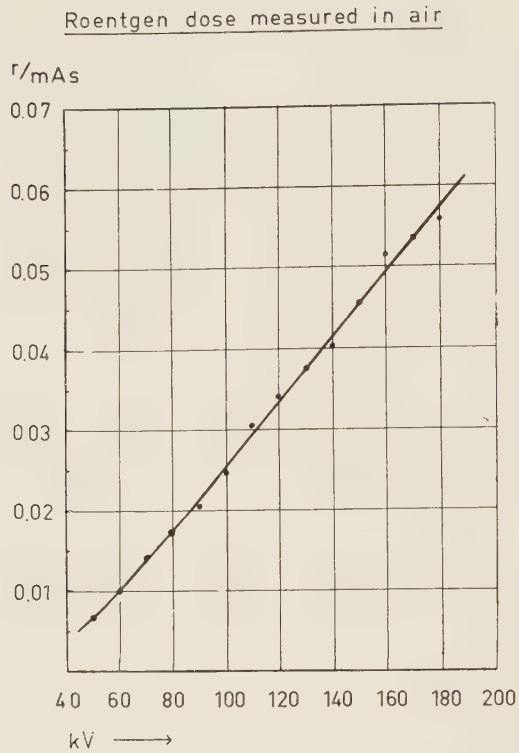


Fig. 6. Roentgen-ray output of the tube in relation to the mAs-value at different voltages. Dose measured in air at 100 cm from focus. Filtration 1 mm Al. Constant potential circuit.

For non-screen film the required mAs-value for unit film density may be taken from the graph in Fig. 4. For this technique, too, the gain with a rise of the kilovoltage seems to be considerably lower above 100 kV than below that level. The values for the power of the voltage (n), which is proportional to the photographic effect, have been derived and are shown in the tabulation below:

Values of n for nonscreen film:

40— 60 kV	3.4
80—100 kV	2.1
130—160 kV	1.6

Measurements were also performed with the special screens for high-voltage work containing barium lead sulphate as the fluorescent agent. The results are shown in Fig. 5. The dotted line, which is introduced for comparison, represents the values of the calcium tungstate screens. There is a marked difference which is most pronounced at about 110 to 120 kV. These screens will be discussed later in the chapter on screens.

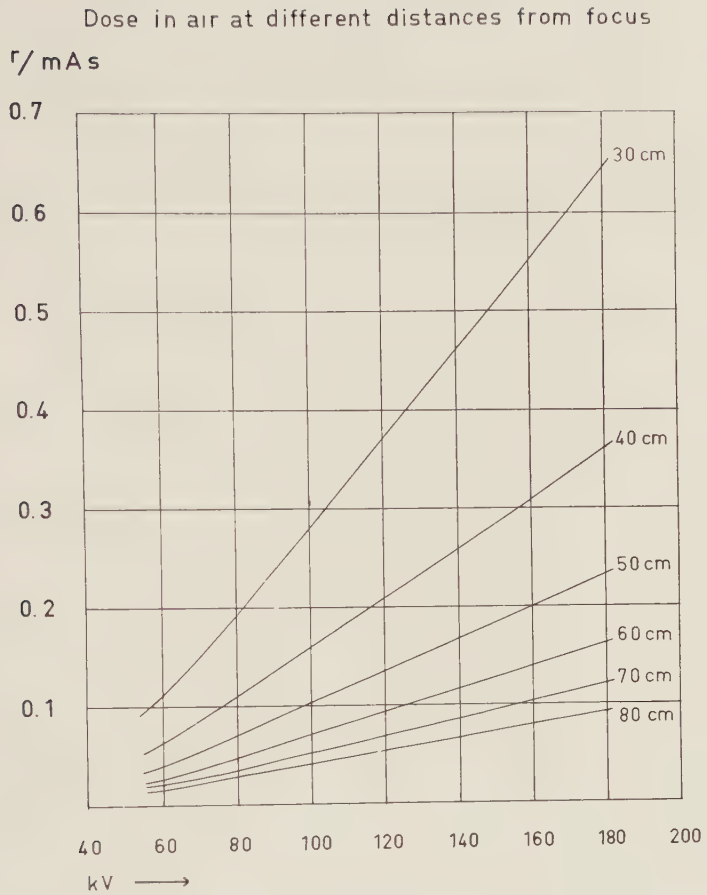


Fig. 7. Calculated roentgen doses at different distances from focus. Note the considerable increase at shorter distances because of the square law.

The radiation dose from different aspects

A question of great interest is the effective radiation output of the tube. The graph in Fig. 6 shows the roentgen ray output of the tube at the same mAs-value for varying kilovoltages. The intensity of the radiation was measured in air and at a distance of 100 cm from the tube. It will be seen that the yield increases continuously at higher radiation energies. The values at 160 kV are thus about five times as large as those at 60 kV. The marked increase in the photographic effect may thus partly be explained by an intensification of the dose obtained.

The graph will give a general conception of the dose obtained from

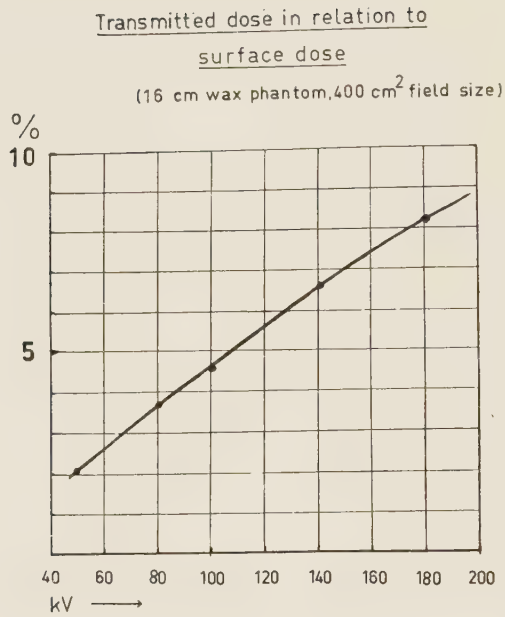


Fig. 8. The roentgen dose transmitted by the object in relation to the surface dose at different voltages. The object and the radiographic conditions correspond to case 1 in Fig. 2.

the tube under conditions typical of diagnostic work. Naturally, the true surface dose of an object will be higher because of backscatter. This, however, varies with the size of the object and the value of dose measured in air is a minimum.

Bearing in mind the fine-focus technique with magnification, in which there is a reduced distance between the tube and the patient, a graph has been made demonstrating the doses in air calculated for varying short distances down to 30 cm. (Fig. 7.) It is surprising that the doses are comparatively so high, which will be explained by the influence of the square law. The magnification principle gives higher patient doses than does the ordinary technique.

These curves may be of a certain interest to every radiologist in routine work. The mAs-value, as well as the voltage, is always known, and the only additional information necessary for an estimate is the distance from the tube. The dose conditions in serial angiography with many exposures as well as in tomography, may easily be approximately estimated for different cases.

In a special series of dose measurements the doses directly connected with the object were measured. The wax body, corresponding to the human abdomen, was studied. The dose on the surface facing the tube

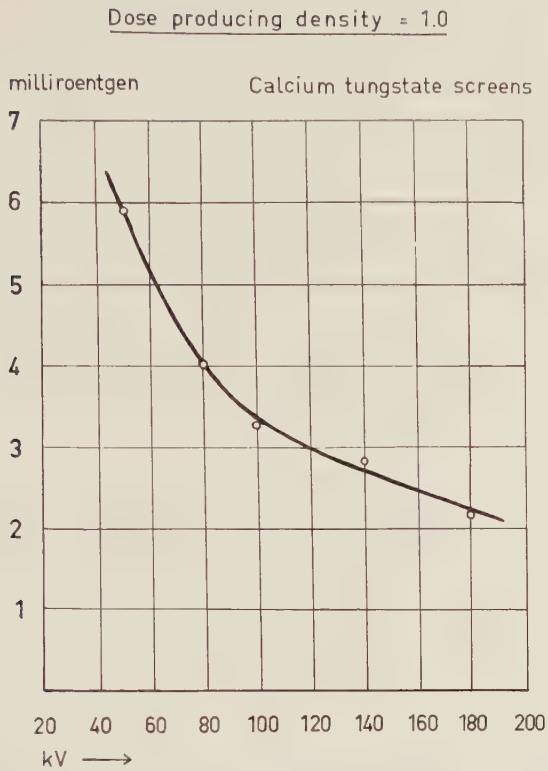


Fig. 9. Roentgen dose required to produce unit density at different voltages. Film with ordinary calcium tungstate screens. (Cea Vicor X film with Patterson Par-Speed screens behind 16 cm wax body.)

was measured and compared with the transmitted dose behind the object, where the film was located. These two dose values are of great interest. They permit a reading of the relation between the radiographically active dose and the surface dose acting on the object, a relation which has quite a different appearance at different voltages. See Fig. 8. The graph demonstrates the percentage of the transmitted dose in relation to the surface dose, which in the interval 50 to 180 kV increases fourfold.

The higher voltage radiation penetrates the body to a greater extent and this is another explanation of the very good photographic effect of the radiation in high-voltage radiography.

A factor of the greatest importance to the patient seems to be the radiation dose on the film necessary for a certain density. Under the conditions of the tests, which correspond to those of the previous investigations, (Figs. 3 and 4) the radiation dose giving unit density was estimated for various voltages. For film with screens the wax body of 16 cm in thick-

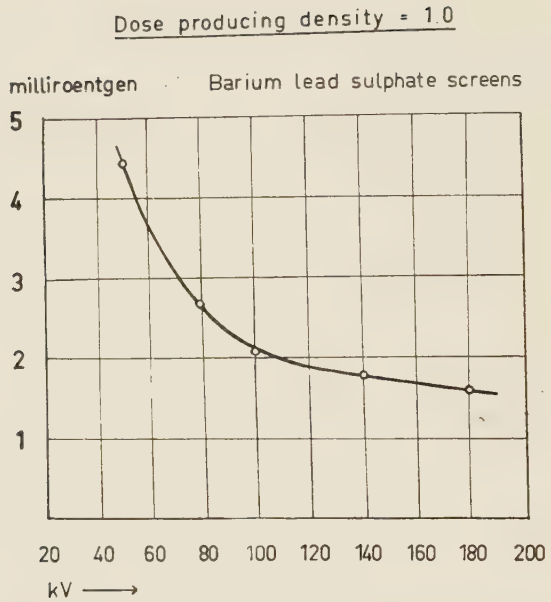


Fig. 10. Roentgen dose required to produce unit density at different voltages. Film with barium lead sulphate screens. (Cea Vicor X film with Kodak type 80 screens behind 16 cm wax body.)

ness was used, and for non-screen film the layer of 8 cm of water. The dose was measured exactly where the film was placed behind the object. The graph in Fig. 9 shows the roentgen ray dose giving unit film density with a typical screen-film combination. The reduction of the radiation required with increased voltage appears considerably less impressive than, for instance, the reduction of the required mAs-value. It should be pointed out that in the case of the latter the changed radiation output of the tube as well as the increased penetration of the object will play an important part. It will be seen from the graph that in the region above about 140 kV the reduction of the required dose is fairly small. With the barium lead sulphate screens this phenomenon is still more marked, which is evident from the graph shown in Fig. 10.

The same measurements with non-screen film and the water phantom are presented in Fig. 11. The graph shows that in this case a continuously increasing dose is required for the unit density with increased voltage. As has been demonstrated by R. B. Wilsey (1951), the curves for the required doses for films of this type show a minimum at fairly low voltages, differing for varying filtration of the radiation. In this case the curve corresponds to the rising part above a minimum situated somewhere below 50 kV. The order of magnitude of the doses required is quite different from that with a screen-film combination.

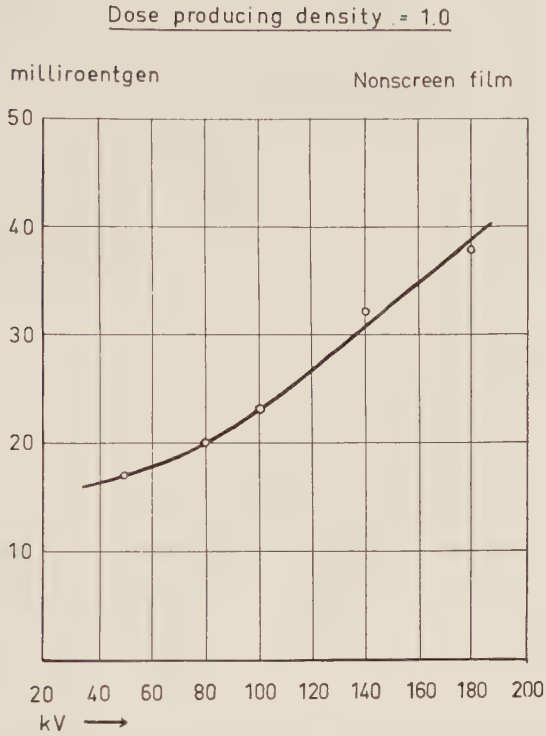


Fig. 11. Roentgen dose required to produce unit density at different voltages with an ordinary non-screen film. (Cea Textur X film behind 8 cm water phantom.)

The dose conditions which characterize non-screen film are not very well known among radiologists and have not been much discussed, possibly because up to the present this type of film has been used exclusively for low-voltage technique. Because of the high definition obtainable with this film, it has been advantageously used also in the angiography of peripheral vessels of the hands and feet. Therefore, this type of material is not without interest in modern angiographic technique. Its special properties in the recording of contrast will be discussed later.

A very expressive illustration of the dosage problem is given by Figs. 12 and 13, which show the size and distribution of doses at different voltages when the film density of 1.0 is attained under the respective experimental conditions. These graphs show the result of the interaction between the different factors influencing dose and density. The effect of the changed penetration as well as that of the changed film sensitivity influence the shape of the graphs. The dotted lines correspond to the logarithmic mean values of surface and film dose. This does not correspond to the proper average dose of the object, as has been shown by

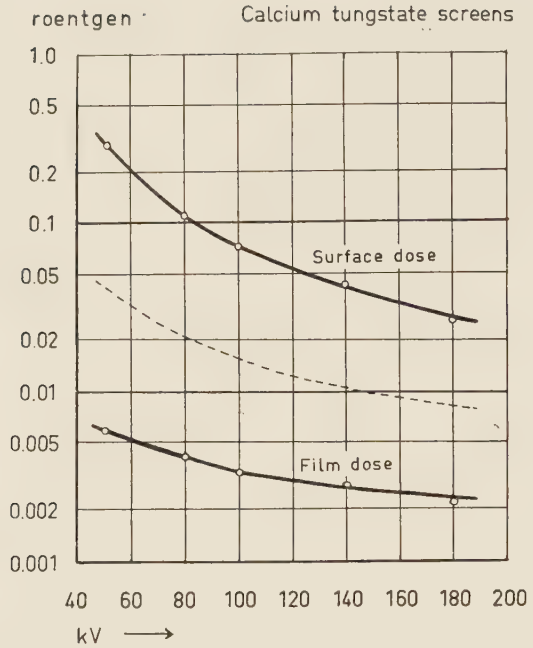


Fig. 12. Dose conditions when the density 1.0 is desired with a film-screen combination (calcium tungstate screens). Wax phantom 16 cm in thickness.

E. D. Trout, J. P. Kelley and G. A. Cathey (1952), and others, and which is explained by backscatter and other factors. It gives, however, a certain orientation regarding the dose within the object.

Fig. 12 shows the conditions with the wax body and a screen-film combination. It will give an objective idea of the dose conditions in radiography at different voltages. In fact, the reduction of dose is not so considerable, especially in the regions of the object situated near to the film. The opinion seems to have been rather too optimistic as regards the doses at higher kilovoltages. Especially with the increased use of serial exposures must the dose be taken into consideration. It is not possible to increase the number of exposures to any large extent with high voltage.

The dose conditions with non-screen film and the 8 cm water phantom are seen in Fig. 13. As shown in the foregoing the film dose required for unit density increases gradually with the increased kilovoltage. Since the object is much more permeable to the higher energy radiation, the surface dose will not increase in the same way. Instead, there is first a decrease to a minimum at about 100 kV and then a very slight increase. These curves show that the conditions are not so very unfavourable as might be expected from the film dose curve alone.

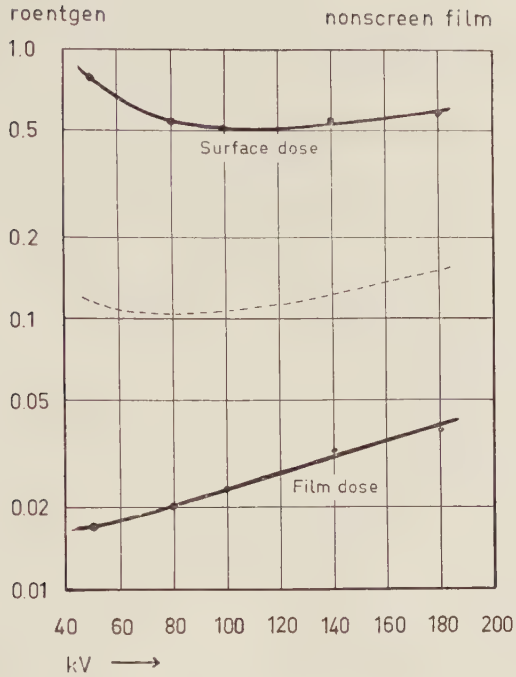


Fig. 13. Dose conditions when the density 1.0 is desired with a non-screen film. Water phantom 8 cm in thickness.

The effect of additional tube filtration

A method of reducing the patient dose in radiography is to use filters checking the softest radiation, which, although producing dosages, is of no value from a radiographical point of view. The problem of additional tube filtration in radiography is of current interest when high-voltage technique is concerned.

The use of additional tube filters was discussed in soft tissue radiography by E. P. Allen and H. W. Calder in 1940. The question of dose was not in the foreground and the filters were intended to give a better visibility of certain details. Similar problems were discussed by S. J. Hawley in 1943. F. Wachsmann, in 1951, reported on the reduction of dose with filters in the voltage region up to 125 kV. Trout, Kelley and Cathey (1952), in a thorough investigation, discussed the influence of different filters upon the dose and recommended, for instance, the use of 3 mm Al up to 100 kV. K. C. Clark, in a discussion of the high-voltage technique in 1953, also recommended a filtration of 3 mm Al. A slight change in picture quality is emphasized by some authors.

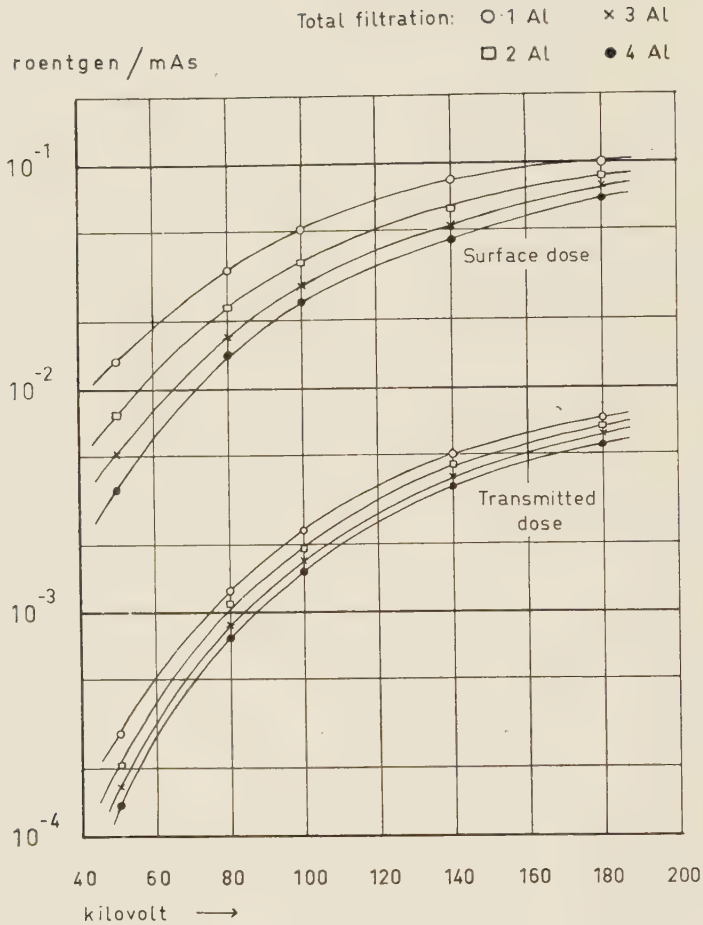


Fig. 14. Surface dose and transmitted dose at different voltages with 1, 2, 3 and 4 mm Al total filtration. Wax phantom 16 cm in thickness.

None of these authors have used higher voltages than 130 kV constant potential. It may be pointed out that it is a generally accepted opinion among radiophysicists that an increased filtration should be of very great importance in all kinds of radiography, ordinary low-voltage technique as well as screening.

In order to study the influence of additional tube filtrations, dose measurements were made with the 16 cm wax phantom and varying added filtration of the tube, which in itself corresponded to 1 mm Al. The results of the measurements of the influence of filtration are assembled in the graph reproduced in Fig. 14. The doses — surface dose and transmitted dose — produced by every mAs at different filtrations

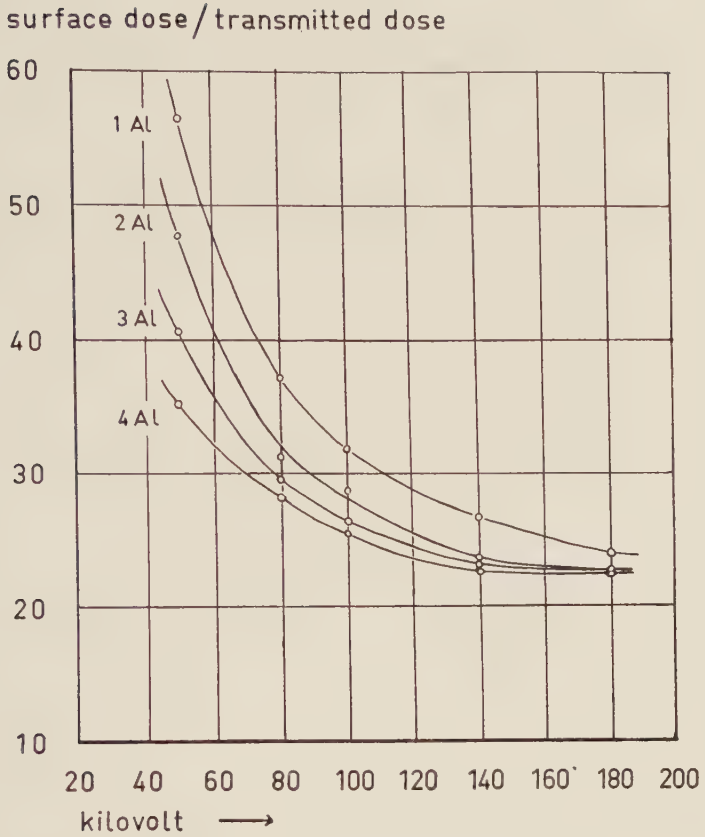


Fig. 15. Surface dose in relation to transmitted dose at different voltages with 1, 2, 3 and 4 mm Al total filtration.

are here plotted against the voltage. Four different degrees of filtration were used, 1 mm (no filter), 2 mm, 3 mm and 4 mm, respectively, each corresponding to one curve in the upper and one in the lower group. With increased voltage there is a considerable gain in the doses produced.

It will be seen from the graph that the filtration causes a marked reduction both of the surface dose and the transmitted dose, that is, the curves with higher filtration run at a lower level. The reduction of the transmitted dose, however, is much smaller than that of the surface dose. The curves of the former are more closely spaced. This means that an increased filtration will give more favourable conditions as regards the patient dose. The most striking difference seems to be obtained with kilovoltages below 100. The effect of different filtration will be most clearly visible if the surface dose is compared directly with the transmitted dose, as in Fig. 15. The surface doses at different filtrations are here

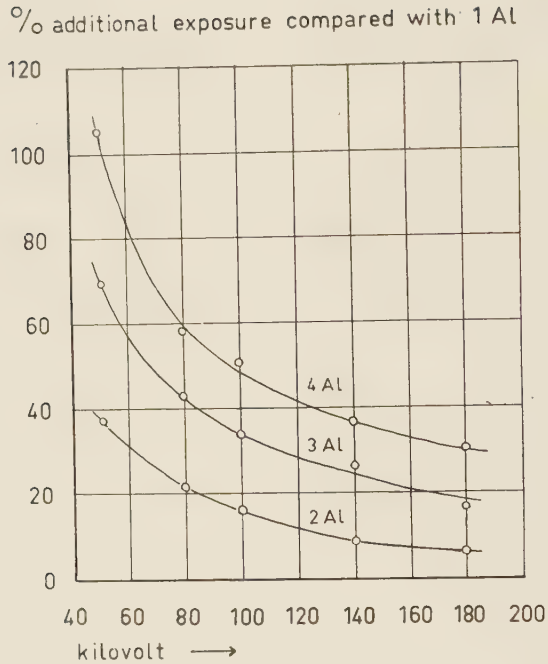


Fig. 16. Increase in exposure required with different filters compared with 1 mm Al.

plotted as multiples of the transmitted dose against the voltages. The lowest filtration possible, 1 mm Al, corresponds to the inherent filtration of the tube. Compared with that, an addition to 2 mm Al gives a fairly considerable decrease of surface dose. The reduction seems to be about 15 to 20 % up to 140 kV, but will be successively lower and seems to be about 10 % at 180 kV. With further additional filtration a still more marked reduction in surface dose is obtained, especially in certain voltage regions. In that respect both 3 and 4 mm Al seem to be useful, and the effect is fairly good at lower voltages but will rapidly decrease, especially above 100 kV. In this region the difference between 3 and 4 mm Al is very small, which means that higher filtration would be without any value. Above 140 kV the difference between 2, 3 and 4 mm Al seems to be slight, although there is a marked difference as against the 1 mm Al filtration. Thus, the increase of the filtration from 1 to 2 mm Al is favourable, but further addition gives no considerable improvement.

In the use of filters one must always bear in mind that they absorb some quantity of radiation and that the exposure must be increased. The graph presented in Fig. 16 demonstrates the effect of different filters upon the exposure. The increase in exposure required to compensate for the reduction of transmitted dose caused by the filter is plotted

against the voltage. The curves correspond to 2, 3 and 4 mm Al filtration and show the percentage of increase in exposure required compared with the conditions at 1 mm Al — the basic value of filtration.

For all voltages the addition of extra filters causes a considerable increase of the exposure required. The higher degrees of filtration, 3 mm and 4 mm, seem to be less favourable, especially in the regions below 100 kV, while 2 mm Al needs only a slight increase in exposure to produce the same dose behind the object. Also from this point of view, it seems to be preferable to use only a moderate filtration.

Conclusions

The investigations have shown that with an increase of voltage there is a considerable decrease in the exposure required for producing a certain film density under ordinary radiographic conditions. This is most marked for the voltage region below 100 kV, but is still very important above that value. There are mainly three factors influencing this change in size of the required exposure.

Firstly, the radiation output per mAs of the tube will increase at higher voltages; secondly, the radiation of higher energies will penetrate the body to a much greater extent and, thirdly, the sensitivity of the most common radiographic material — the screen-film combination — will be increased to radiations produced at higher voltages.

The non-screen film will show a decreased sensitivity to radiation produced at higher voltages, but the other factors compensate, and the required exposure for unit film density will, in fact, show a marked reduction with raising of the voltage.

The dose on the surface of the object is related to that behind it in a manner typical of each voltage. The dose behind the object, necessary from a radiographical point of view, depends on the radiation sensitivity of the photographic material in question.

Additional aluminium filters change the relation between the surface dose and the transmitted dose in a favourable manner, but reduce the effect of exposure to a certain extent. The best results will be obtained with a moderate filtration.

THE CHANGE IN CONTRAST OF DIFFERENT SUBSTANCES WITH VARIATION IN THE VOLTAGE

Introduction

It was decided that a proper conception of the influence of voltage upon the contrast of different substances was required and, with this aim, a series of tests were made in which small quantities of the respective substances were depicted radiographically and the density values measured. Density curves were worked out simultaneously and the variations of contrast could then be determined, not only as density variations, but also in relative intensity values applicable for different photographic techniques. The contrast at a desired density level with an arbitrary technique could then be calculated.

The substances to be studied were those of special interest from a radiographic point of view. The angiographic contrast media examined were *Umbradil* (a water solution of the diethanolamine salt of 3,5-diiodo-4-pyridon-N-acetic acid produced by Astra, Sweden) and *Urokon* (a water solution of sodium 3-acetyl-amino-2,4,6-triiodobenzoate produced on American licence by Pharmacia, Sweden).

The contrast media used for the stomach and the intestines were represented by water suspensions of barium sulphate (standard preparation labelled *Unibaryt*). The bone substance was represented by calcium sulphate in the form of plaster of Paris, a material easy to use in tests of this nature.

Water and paraffin were also studied as comparisons, the former as a substitute for soft tissues generally and the latter as representing body fat.

Experimental technique

The roentgen tube used in the experiments was the same as the one employed in the other investigations reported in this work. Its inherent filtration corresponded to 1 mm Al. A constant potential circuit was used and the focus-film distance was 100 cm.

Both film with screens and non-screen film was used, ordinary calcium tungstate screens of medium speed being employed in the former

case. Special test series were carried out to produce density curves with which the densities could be translated to relative intensities. In the case of the film with screens, special precautions were taken to eliminate the influence of reciprocity law failures.

To produce a radiation quality approximately equal to that present in ordinary radiography, a wax phantom, 16 cm in thickness, was used through which the radiation passed before it penetrated the different substances under study.

The contrast media and the test chambers

Especially constructed containers were employed for all fluid substances studied, permitting radiography with a horisontal direction of the rays. The size of these varied so that the requirements of different substances were satisfied. The containers consisted of glass tubes, 30 mm in diameter, which were carefully cut into different lengths. Two covers of very thin plain glass were cemented to each end of the sections and suitable small chambers thus produced. Fig. 17 shows a series of these experimental vessels of various dimensions. The narrow vertical tubes to the right were used in preliminary tests in the choice of a suitable thickness of the layers to be studied; these tests were very easily made with a vertical direction of the beam of radiation.

The chambers with contrast media and other substances were filled just before the examination through very small openings with the help of a syringe and a fine tube; these were then covered with glue to prevent evaporation of the solutions.

The barium sulphate suspensions were at first used in ordinary liquid form, but considerable sedimentation occurred in the course of the experiments, and it was necessary to make the chamber contents solid. An addition of a very small amount of gelatine did not change the radiographic character of the substance, and if the heated suspension was rapidly cooled and at the same time agitated, a homogeneous mass was obtained and was very suitable for the tests. The concentration of barium powder was carefully adjusted to correspond to the concentrations used in the routine work of the department in stomach and intestinal examinations. This adjustment was performed by means of the hydrometer principle which has earlier been thoroughly discussed in a paper by the writer (1953).

The calcium sulphate in the form of plaster of Paris as well as the melted paraffin was also poured into the glass vessels.

The layer thickness of the different substances was adjusted to produce a reduction of the radiation easy to record within the optimal density range with due regard to the radiographic material and technique.

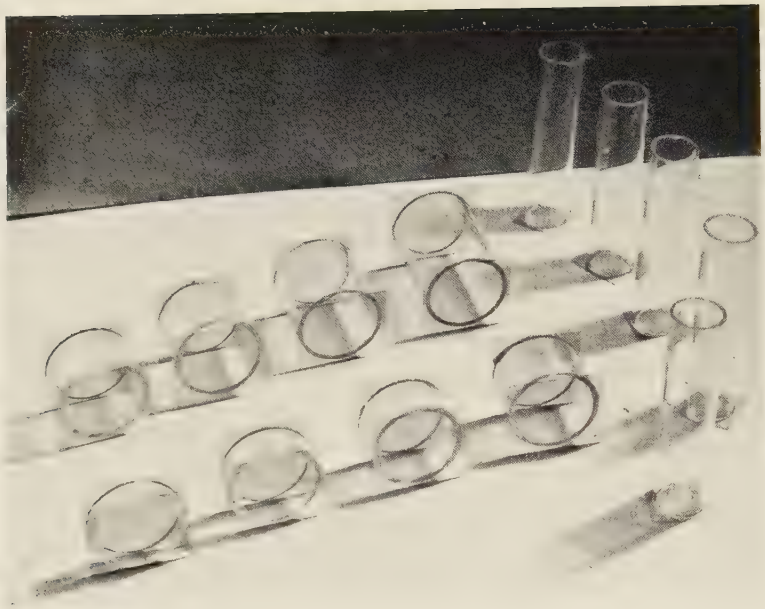


Fig. 17. Different types of chambers used in the studies of contrast media. Thin glass plates have been cemented to glass tubes of various dimensions. The set of vertical tubes on the right has been used in some preliminary tests, the others in the principal tests with horizontal direction of the radiation.

A complete set of the chambers, filled with the respective substances, was ordinarily depicted on each of the test films. They were placed close to each other, and centered so that the beam passed perpendicularly to their valls. Lead plates screened off all unnecessary primary and secondary radiation; the amount of such radiation, not eliminated, could be determined separately, since small lead strips were arranged beside the chambers. This adventitious radiation seemed to be homogeneously spread over the film, which was situated 5 cm behind the chambers. Fig. 18 demonstrates the experimental arrangements in a simplified manner.

Exposure, processing and measuring of the films

The range of voltage from 50 to 180 kV was utilized and ordinarily the exposures were made at intervals of 20 kV. The final series of exposures were an outcome of many preparatory tests and the experimental conditions were varied in different ways until the ultimate films were made.

The choice of exposures for the films, both those with screens and those without, were made strictly in accordance with the curves for mAs required for unit film density, which were presented in an earlier chapter.

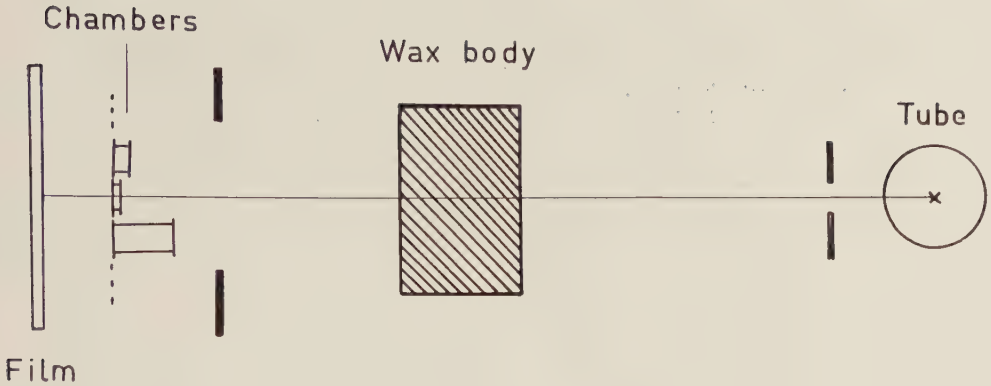


Fig. 18. Experimental arrangement for the study of variation in contrast. The media to be studied are enclosed in the test chambers.

There was a striking homogeneity in the density produced in that way, and the films confirmed the correctness of the investigations of the exposure required.

The processing of all films of one and the same series was made at the same time. The technique for the darkroom procedure was exactly the same as for all other radiographic investigations earlier described in this book. The developer, which was of the composition described on page 24, was used at 20° C (68° F) with constant agitation for 4 min.

The measurement of the density of the films was performed with an electric densitometer. The round areas corresponding to the chambers depicted were each measured at different points, the recorded readings corresponding to a mean value. The density behind the lead strips was measured at different points as well as the density surrounding the test chambers corresponding to the radiation which had not passed through the test substances. An empty chamber was also measured to obtain a value of the influence of the glass walls. All values have been corrected for the influence of secondary radiation.

Results of the investigation

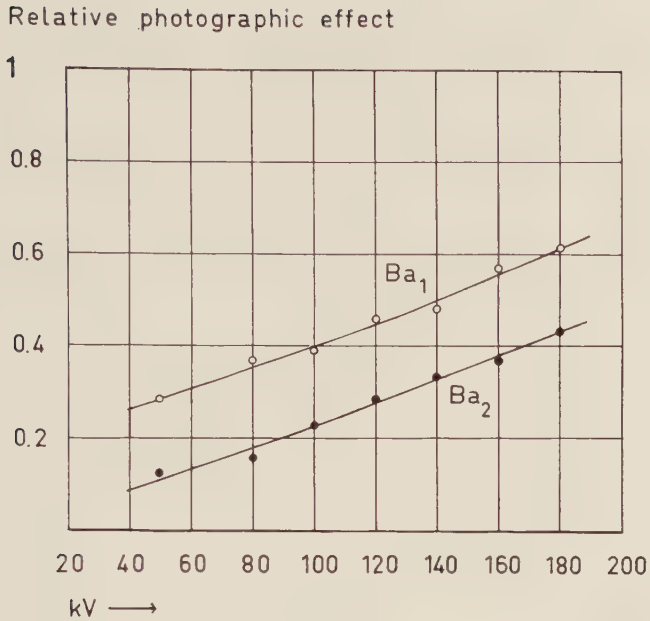
The values of density read at the different points of the films were translated to relative radiation intensities, and it was then possible to evaluate the change in the effect of the respective substance upon the radiation with the variation in voltage. It would be more correct to speak about the change in the ability of the substances to reduce the density-producing effect of the radiation. It seems to be wrong to speak merely of absorption when the recordings of contrast are made by photographic means. The recorded density certainly depends partly on the absorption

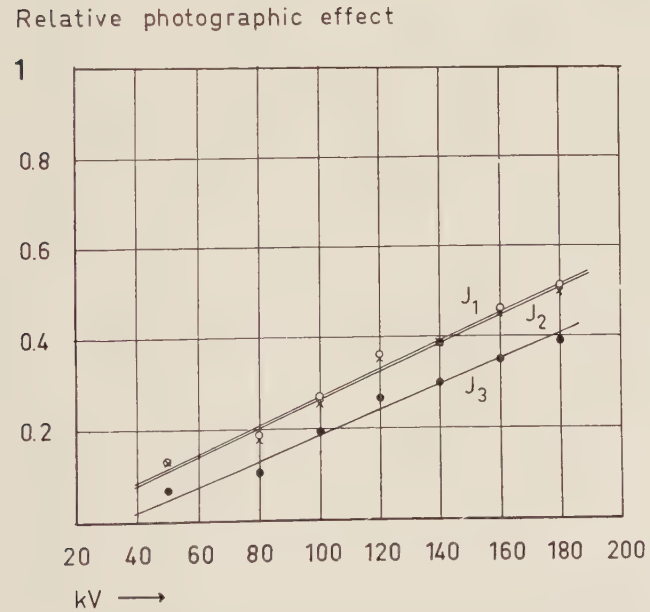
conditions, but a very important factor is the specific sensitivity of the radiographic materials to the radiation. The rays which have passed through a layer of contrast medium have changed character qualitatively compared with those which pass only through the light soft tissues surrounding for instance a blood vessel. It is not only a matter of two different amounts of radiation, but also of two unequal qualities. As will be shown in the present investigation, the recording of contrast will be quite different with non-screen film than with ordinary films used with screens. These two types of radiographic material, in fact, have very different types of radiation sensitivity.

All possible variations in layer thickness may occur in daily routine work. In an investigation like this one, which always must be very approximate, it is not possible to reproduce many different conditions. The properties of the different substances have therefore been studied at certain fixed layer thicknesses, which are presented in the respective diagrams. The studies reported give a general idea of the variation of recorded contrast with the voltage.

The determination of contrast in this investigation refers to the difference in density of the film between the regions of the recorded substances and their surroundings. As all substances investigated have been examined in air, it is most correct to consider their opaqueness to be correlated to that which is obtained when the same space is filled with air. From a practical point of view the density values which are read may be said to refer to the radiation *before* and *after* passing the respective contrast medium. The primary radiation entering the substance studied has a quality similar to that in ordinary radiography since it has passed through the wax body.

Figs. 19 to 21 show a selection of experimental results with a *screen-film combination*. The density values have been translated into values of relative intensity of the primary radiation, presuming that there has been no change in its quality. The relative photographic effect of the primary radiation is given the value 1. The curves demonstrate the apparent remaining intensity as if the quality were unchanged after passing through the different substances. Because of the actual change in quality and the peculiar sensitivity conditions of the radiographic material the recorded density values will thus not represent the true intensities of radiation measured dosimetrically behind the chambers. It seems to be very appropriate to use the conception *photographic effect* of radiation instead of intensity, and in these special tests, the expression *remaining photographic effect*, which independently of intensity or quality indicates the *real* contrast possibilities with the radiographic material in question. The visible picture contrast in the film will then depend on the processing technique.





Figs. 19 and 20. Remaining photographic effect of radiation after passing through layers of different substances. Typical *screen-film combination*. Incident effect = 1. Ba_1 = 8.3 mm of barium preparation for colon examination. Ba_2 = 6.1 mm of barium preparation for examination of the stomach. J_1 = 5.1 mm of Urokon 40 %. J_2 = 5.1 mm of Umbradil 50 %. J_3 = 9.9 mm of Umbradil 35 %.

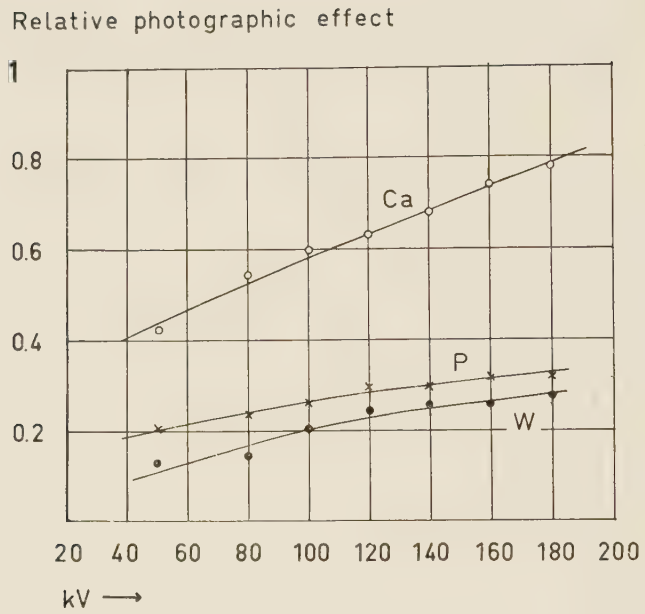


Fig. 21. Remaining photographic effect of radiation after passing through layers of calcium sulphate, paraffin, and water. Typical *screen-film combination.* Incident effect = 1. Ca = 5.2 mm of calcium sulphate in the form of plaster of Paris. P = 70 mm of paraffin. W = 70 mm of water.

Fig. 19 shows the remaining photographic effect behind two different barium suspensions, one of the concentration ordinarily used for colon examinations and the other a preparation suitable for examination of the stomach. The respective layer thickness is shown below the diagram.

Three different types of angiographic contrast media are shown in Fig. 20. Of these Urokon 40 % and Umbradil 50 % seem to have practically identical curves. Umbradil 35 % has a lower opacity, but has here been used in a thicker layer.

In Fig. 21 is shown the remaining photographic effect behind a layer of calcium sulphate. Water and paraffin have also been studied for comparison with similar exposure conditions. With these substances considerably thicker layers must be employed in order to obtain a reduction of the photographic effect of a size comparable with that of the contrast media. The layers have ordinarily been at least 7 times thicker.

It must be emphasized that the thicknesses of the respective layers have all been chosen to give densities within the optimal range of densities for the films and to make possible the exposure of many substances simultaneously on the same film.

It is obvious that at 50 kV, for instance, a 5.1 mm layer of a iodine preparation has about the same radiographic opacity as 8.3 mm of a barium sulphate suspension suitable for colon examinations. The same effect upon the radiation is also produced by a 70 mm layer of water. At 180 kV, however, the difference is considerable between the water and the heavy substances.

As shown in Figs. 19 to 21 the increase in voltage will cause a considerable increase of the remaining photographic effect behind the different substances. This means a loss in contrast, which is of very great importance. An idea of the individual reduction in the capacity of checking the radiographically active radiation is given in Fig. 23. The ability of producing contrast at 50 kV represents 100 % and the variation with the voltage for five selected substances is shown. The curves are calculated from the earlier diagrams of remaining photographic effect according to Fig. 22. The distinct change with the calcium preparation corresponds to all practical experiences of daily routine work. The light substances show a moderate change, which was also to be expected from earlier discussions. The heavy substances, which keep company, show a fairly pronounced change.

The value of *air* as a contrast medium in radiography depends on the surrounding substance. A quantity of air inside a body gives practically the same effect as if a corresponding volume of the tissue had been removed. The character of this tissue will in every case determine the contrast obtained as well as its change with variation of voltage. The very slight change of the contrast of the light substances is the basis for the relative good results of chest radiography at higher voltages, in which air is contrasted against soft tissues.

With *non-screen film* the curves of the remaining photographic effect behind different substances have quite another appearance. There is a considerably lower rate of change than when film with screens was used. The variation of the photographic effect lost in the substances — the relative contrast — is shown in Fig. 24, presented in the same manner as in the previous figure. It is obvious that, for instance, the heavier substances such as the iodine and the barium salts in the tests show a change which is only one-third as rapid as with the screen-film combination. Furthermore the calcium salt is well preserved.

This is a very peculiar phenomenon which can be explained by the difference in sensitivity to various qualities of radiation. The same radiation behind a heavy substance will give quite different recordings depending on the radiographic material. The film with screens which has proved to have an increased sensitivity to hard radiations will produce a higher density than the non-screen film, which has a decreased sen-

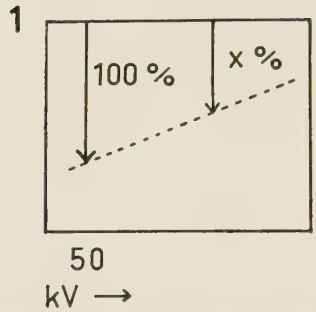


Fig. 22. Principle of calculations of relative contrast from diagrams of remaining photographic effect (Figs. 19 to 21). The photographic effect lost in the object at different voltages is compared with that at 50 kV (= 100 %).

sitivity for harder rays. This means that the heavier substances will seem to be more opaque when recorded on non-screen film. With that material the picture contrast should be better preserved in spite of a high increase in the voltage.

The phenomenon described appears especially pronounced on certain occasions in the daily routine work, and will not infrequently confuse the radiologist. An example will be briefly related. For fractures of small bones, for instance in the hand, ordinarily non-screen film is used. After reduction and the application of a plaster bandage, control radiographs, also on non-screen film, are obtained. It is then perplexing that the plaster is so extremely dense and that the necessary increase in voltage is relatively great, especially compared with a case of a screen technique.

Another peculiarity of the non-screen material, which may also be explained partly by its sensitivity characteristics, is its reaction to secondary radiation. With an increased sensitivity to softer rays one must count upon a more marked recording of the secondary radiation, which is softer. A certain difference was verified, but one must take into account the influence of the cassette wall and front screen, which disturbs a comparison between the two materials.

In these investigations the chambers were situated in air. It ought to be pointed out that there must be a certain difference compared with the conditions in practical radiography, in which the quantities of contrast media are introduced into the body. In fact, the amount of the dense substances will take the place of a similar amount of soft tissue and somewhat other conditions than those represented in the experiments will occur. The soft tissues, however, were found to have so comparatively small an effect upon the radiation compared with the heavy substances that the difference will be of a fairly small order, whether one takes into account the effect of the quantity of soft tissue displaced or not.

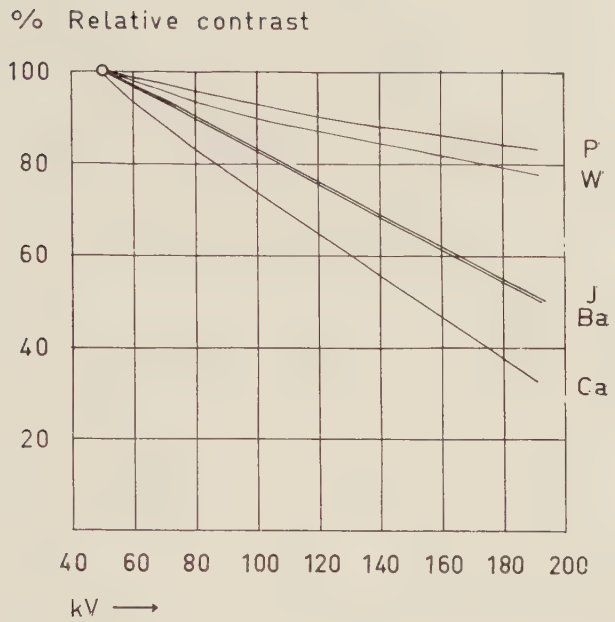


Fig. 23. Relative contrast of some different substances recorded with a *screen-film combination*. 50 kV = 100 %. (Compare Fig. 22.) The symbols are identical with previous diagrams ($Ba = Ba_1$, $J = J_1$).

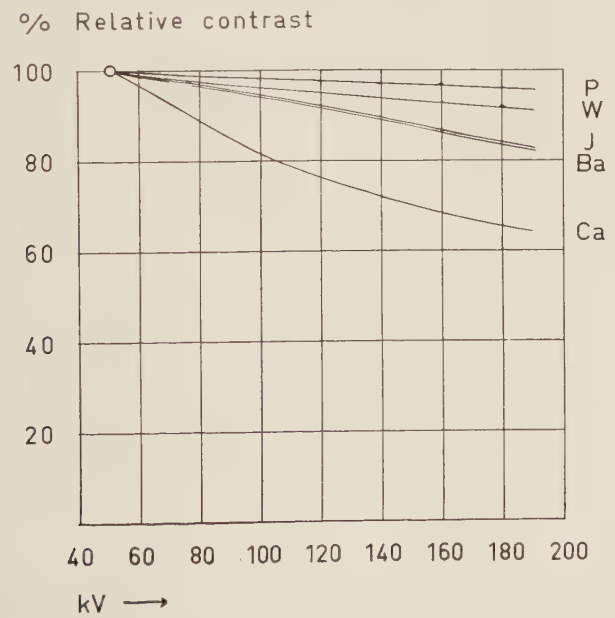


Fig. 24. Relative contrast of some different substances recorded with *non-screen film*. 50 kV = 100 %. (Compare Fig. 22.) The symbols are identical with previous diagrams ($Ba = Ba_1$, $J = J_1$).

Conclusions

The photographic effect of the radiation, which is lost during the passage of the latter through a layer of a substance, will be reduced with increased voltage, which means a reduction in contrast. Because of the sensitivity characteristics, film with screens will show a much more marked reduction in recorded contrast than non-screen film which preserves the contrast better at higher voltages. Layers of contrast media containing iodine used in angiography, barium sulphate preparations, calcium salt, water and paraffin, have been studied and compared. The investigations have shown the considerable reduction in contrast with iodine and barium, indicating that all efforts should be made to obtain new contrast compounds of still greater relative opacity. The calcium salts stand apart by their exceptionally low contrast at the higher voltages, which speaks against the use of such voltage regions for all skeletal objects. The soft tissues are comparatively much better preserved.

It must be emphasized that at present it seems to be impossible to maintain the same contrast possibilities at the higher as at the lower voltages. The use of non-screen film does not solve the problem, its lower general sensitivity and other properties making this material not very suitable.

RECORDING OF CONTRAST AS A PHOTOGRAPHIC PROBLEM

The density curve and the importance of gamma value

The density or characteristic curve is a fundamental photographic factor. It gives an illustration of the possibilities of the photographic technique used to record the radiographic object. In high-voltage technique, where the problem of contrasts is always real, the possibilities present of rendering contrasts may be estimated from the slope or gradient of the curve.

The density of an image is a measure of its light-stopping power in logarithmic terms. Graded series of exposures are given to a film and after accurate processing the densities are read on a densitometer. The density values are plotted against the logarithmic intensity values of the exposure. The characteristic curve of a photographic emulsion consists of three parts: the underexposed region; the straight line portion, where the density is in proportion to log exposure; and the region of heavy densities where the curve flattens.

The tangent of the angle which the straight line portion of the curve forms with the log exposure axis is known as the gamma, and is a measure of the contrast, *i. e.* the rate at which density grows as exposure increases.

The range of densities which is useful for radiographic purposes extends, according to J. Eggert, in density values from about 0.5 to 2.0 or 2.5, the higher value relating to viewing conditions especially favourable. H. Chantraine (1933) mentioned densities of 0.6 to 2.6.

The density ranges discussed above coincide with the straight-lined portion of the curve, which ordinarily starts at a density of about 0.5.

The gamma value, which for ordinary photographic material never exceeds 2, is much higher for radiographic films, because of their double emulsions. The value depends partly on the developer, partly on the material in itself, but is often more than 3.0. For radiographic purposes, mainly two different kinds of developers are used. Normally the ordinary developers contain sodium carbonate as the alkali, but the newer type of rapid developers marketed, whose importance is increasing, contain sodium or potassium hydroxide, giving higher contrast and shorter developing time. The developing agents are practically always metol and hydroquinone.

The difference in obtained gamma value will not be so high, but one of the firms reports that the maximum gamma value obtainable should change from 3.0 to 3.5 with the two different types of developer. (Gevaert 209 A and 230, respectively, with Curix film.)

The general opinion is that the use of screens should increase the contrast materially. This is the case when comparing the result of a non-screen exposure on a film designed for screens with an exposure made with screens. The increase in contrast is then striking. The non-screen film is of a different photographic character to the ordinary roentgen film suitable for screens. It has a thicker emulsion layer with much larger quantities of silver. According to measurements which I have made on different manufacturers' products, the coating thickness is about 30 % greater with the non-screen film. The content of silver salts of the coating of a typical non-screen film is reported to be related to that of a film for screens as 1.0 to about 0.6. For the particular film used in the investigations of this work the quantity of silver bromide amounts to 38 g and 22 g, respectively, per square metre. The properties of the emulsions also differ in other respects and each type of film is best suited for its special purpose. With the non-screen film, it is thus possible to obtain very good contrast up to and about 3.0 in gamma with suitable development. This is partly due to the thick emulsion layer, which increases the contrast in the same way as a double-coated film compared with a film with one-sided coating. For non-screen work it is natural that a thicker emulsion layer, rich in AgBr molecules, must be more sensitive to radiation than a thinner and poorer one.

The importance of the optimal rendering of contrast will be readily seen from an example. We may assume that a radiographic object is roentgenographed with a film which is developed to a gamma value of 2.5 instead of the possible 3.0. The reason may be an exhausted developer, a too cold one, or too short a time. The effect of the lower gamma value is a reduced difference in densities between, for instance, an important detail and its surroundings. The practical consequence is reduced visibility of detail. To obtain the same visibility, the primary object contrast must be increased either by lowering the voltage and thus producing more favourable absorption differences in the object, or by an increase of the concentration of the agent in a contrast medium examination.

A calculation from characteristic curves with gamma values of 2.5 and 3.0 will show that the differences in radiation intensity which give the same density difference in the film are related to each other as 2.5 to 3.0, that is, 5/6 or 84/100. From the measurements of the contrast of various media presented previously, I have calculated how to compensate the reduced rendering of contrast typical of the lower gamma

value. With a reduction of the kilovoltage, a suitable effect is obtained with a change from 100 kV to 50 kV or from 140 kV to 100 kV. This refers to ordinary contrast media. The values must be considered as very approximate and are depending on the substances concerned. However, the figures illustrate strikingly the immense importance of a high gamma value, and, reversely, it may be said that every possible increase in the gamma value materially extends the possibilities of the high-voltage technique.

The influence of different voltages

A question of interest is whether the voltage has any influence upon the characteristic curve. H. E. Seemann (1950) showed that there was no systematic difference in the shape of the density — log exposure curve for various wavelengths of roentgen radiation tested by him. Several authors, for instance G. E. Bell (1936), had earlier demonstrated the independence of roentgen ray wavelength. H. S. Tasker (1945) in a study of screen properties also showed that density curves for screen-film combinations at different kilovoltages and filtration had the same shape and gamma value.

The density curves of the photographic material used in the investigations of this work are demonstrated in Fig. 25 and 26. Of these, the first is a characteristic curve of non-screen film (Cea Textur X. Emulsion number 050,376), which was processed with agitation in the developer described on page 24, a typical roentgen film developer. The film dose was measured with an ionization chamber in the same manner as all other dose measurements made for this book. Normal radiographic conditions were created. The radiation acting on the film had passed through 80 mm of water and the tube filtration was about 1 mm Al. A constant potential circuit was used. The three parallel curves correspond to 50, 100 and 180 kV, respectively. There is practically no difference in the shape or slope of the curves. They are situated with a small space between them which is explained by the variation in sensitivity to radiation with the voltage. The curve corresponding to the highest voltage is situated farthest to the right, which means that this material is less sensitive to the radiation in this voltage region. I should here like to refer to the curves of doses producing the density = 1.0 for different materials shown on pp. 33, 34, and 35. There is a typical reduction of sensitivity with increase of voltage when no screens are used.

Fig. 26 shows the characteristic curves of a screen-film combination. A pair of calcium tungstate screens (Patterson Par-Speed) were used with an ordinary roentgen film (Cea Wicor-X. Emulsion number 011,081), which has been processed in the manner described previously. Again in

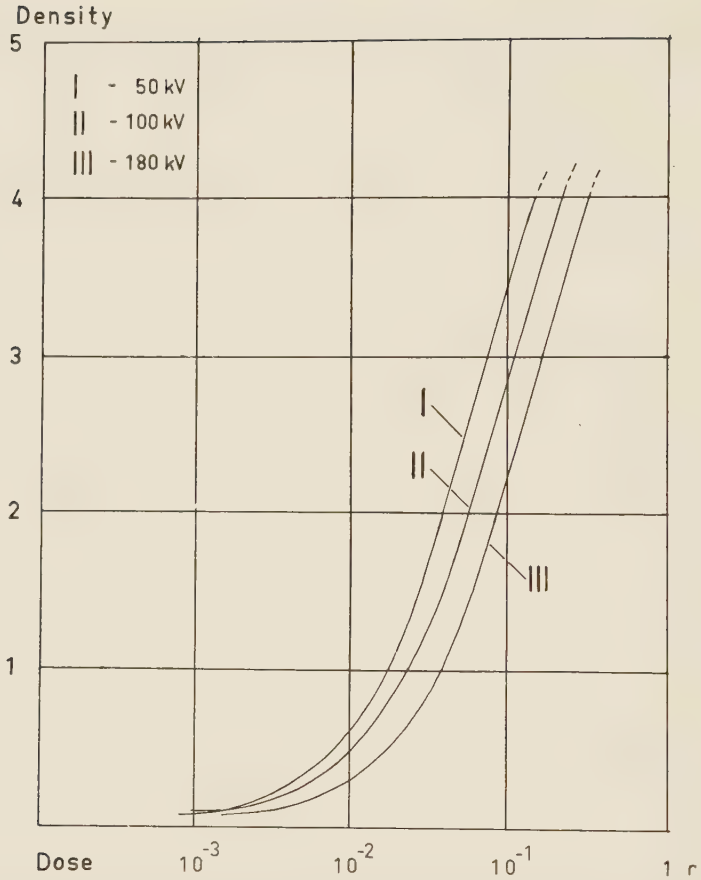


Fig. 25. Density curves of a non-screen film at different voltages. Radiation quality corresponding to ordinary radiographic conditions. Constant potential circuit. Roentgen film developer with agitation. Note the reduction in sensitivity at higher voltages.

this case, there is no difference of importance between the shape of the curves. Increase of voltage in this case gives an increase in sensitivity to radiation. The arrangement of the curves for different voltages is here inversed compared with Fig. 25. With barium lead sulphate screens a similar shape and gradient of the curves was obtained.

The gamma values obtained for the two types of material are 3.0 and 3.5, respectively. These values seem to be rather high for the developer, which contained no strong alkalis. An important factor may be the constant agitation with a paddle, which gives an increased developing intensity (R. Herz and F. Luft 1933). In addition, the photographic material itself, especially the non-screen film, was known to possess a very good contrast.

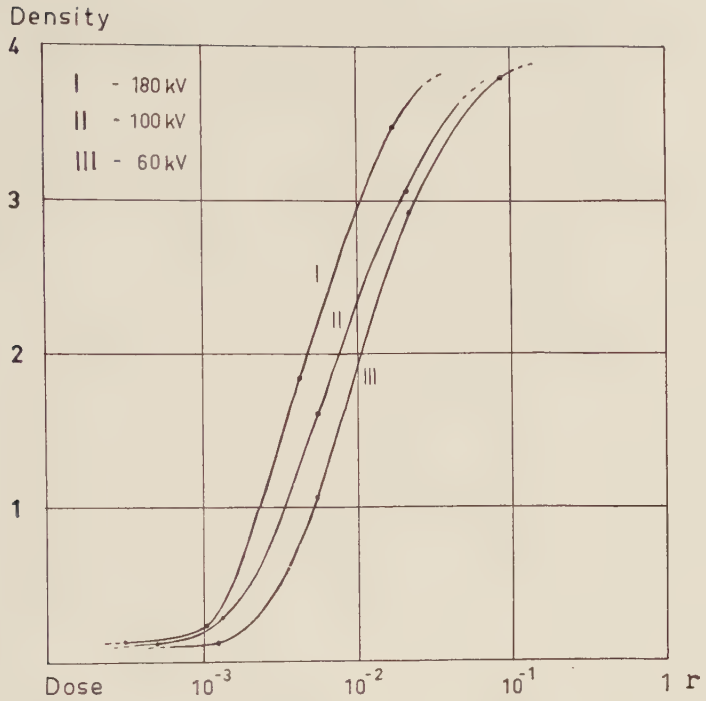


Fig. 26. Density curves of an ordinary film-screen combination at different voltages. Radiation quality corresponding to ordinary radiographic conditions. Constant potential circuit. Roentgen film developer with agitation. Note the increase in sensitivity at higher voltages.

General aspects of development

Because of the extreme importance of an optimal density curve in the processing when high kilovoltages are used, increased attention must be paid to the development.

This process must produce the highest possible contrast and must be constant from day to day. The variation of the characteristic curve with different development times is of very great interest. The curves previously demonstrated correspond to the optimal developing condition. Fig. 27 demonstrates the difference in the rendering of contrasts at various development times. The density curves were made with a typical screen-film combination, the same material and emulsion number as used for the other investigations. The curves which correspond to certain intervals of development illustrate the successive increase in the rendering of contrast during the development. The necessity of using a suitable developing time is evident.

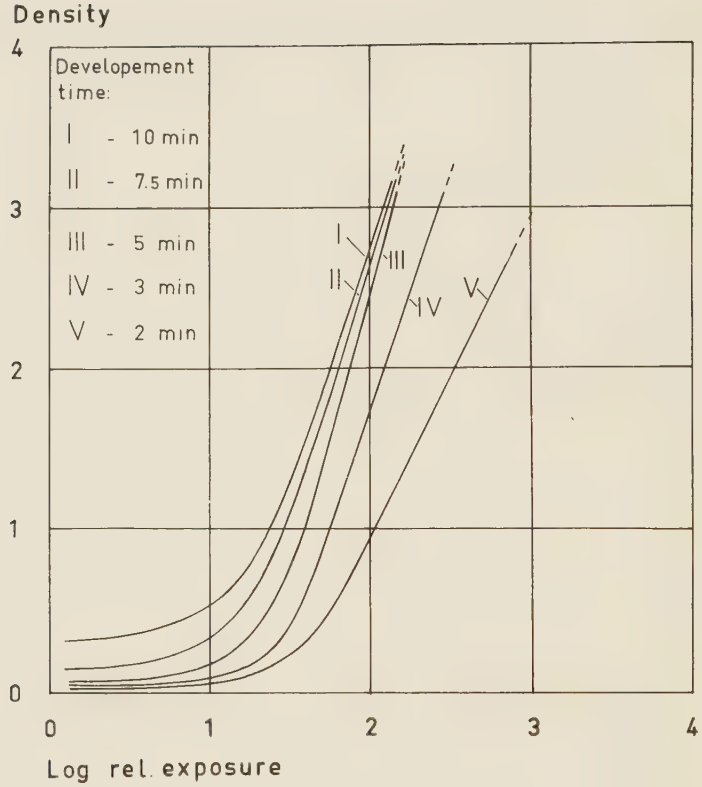


Fig. 27. Density curves of an ordinary roentgen film with screens (visible light). The series of curves is obtained with different development times. The slope of the curve (gamma) is seen to increase to a certain value. Compare figure 28, where gamma is plotted against time of development. Note the considerable increase of fog at very long development times. Roentgen developer with constant agitation (compare page 24).

In Fig. 28 the gamma value is plotted against the time of development. It will be clearly seen that a development of 4 or 5 minutes gives a superior contrast in this case. A shortening of the time of development is detrimental if maximum of contrast is desired. An increased development will also give a reduction of contrast, but a higher density (measured above the fog). This means that the density output of the irradiation will be higher. Fig. 29 shows the variation of 'speed' with the developing time, when 5 minutes represents 100 %. The practical consequence of this fact is that one cannot make use of the maximum speed of the film without a loss in contrast. With a long developing time there will also be a considerable increase in fog. Note the increasing height of the initial horisontal part of the curves with prolonged developing time in Fig. 27. The potential tendency of fogging depends on the age of the material.

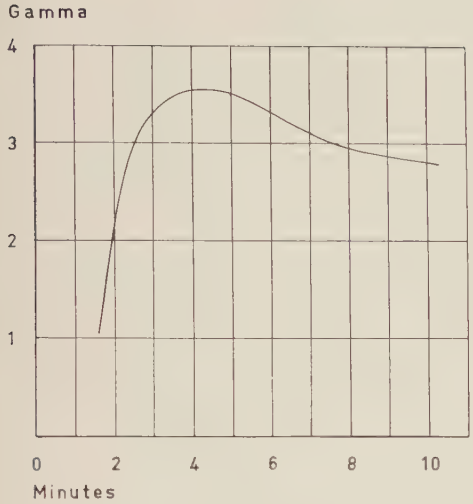


Fig. 28. The slope of the density curve — gamma — plotted against time of development. The gamma-value represents the ability of rendering contrasts in radiography.

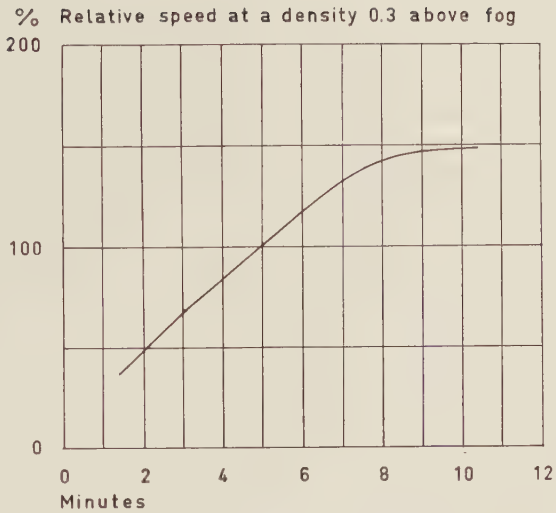


Fig. 29. Variation of roentgen film 'speed' with time of development. 5 min. development represents 100 %.

Experiences from departments with manual development show that the films will often not be sufficiently developed and that a too low gamma value is obtained. The explanation of this is in no way surprising. Some films may be overexposed to a small degree and these are moved from the developing bath earlier than usual so that they may not be too dark. The personnel producing the radiographs will quickly be accustomed to higher exposing of the radiographs as these, unlike those underexposed, can always be 'corrected' in the darkroom. The darkroom staff then develop all films for shorter times than normal since accurately exposed films will also give results which do not appear too thin.

In this way one has unconsciously accepted a technique which involves a shorter development time and greater possibilities of levelling differences in exposure. This technique, however, is quite incorrect and the imagined advantages are of no value since there is an immense reduction of the rendering of contrast — the gamma value will be too low. It will be seen from the series of curves in Fig. 27 that a short development gives a less marked reduction of the lower densities and the films will therefore not appear to be very thin. At the same time it is surprising that the ability of the eye to judge contrasts is so low and that only comparison with a correct film makes it possible to recognize the striking difference. It is a well known fact that, on comparing films of the same patient from repeated examinations, there is often a marked variation in quality. There is an intimate relationship between uniformity in the processing result and the contrast obtained. When the processing method gives an optimal rendering of contrast there will also be a uniform and high quality. Another very common observation is that the contrast is very good when the developer is fresh but that it gradually decreases with the reduced chemical activity of the solution. This fact is often not fully observed until the day when new and fresh developer is introduced. The change in the quality is then often surprising. These incorrect results are due to an incomplete knowledge of the principles of optimal utilization of a developing solution.

Ways of obtaining uniform development with high contrast

There are different methods of processing sheet radiograph film to render an optimal result possible.

The *mechanical* principle will be briefly mentioned. Developing machines, which are increasingly employed, consist of an automatic processing unit, in which the processing cycle, ordinarily including drying, is performed mechanically. The only manual operations required in the darkroom are those of placing the films on the hangers, and introducing these into the machine. The transfer of the films from one bath to the next is automatic. The duration of the development is adjustable, as is the control of solution temperature. The developing action of the chemicals is kept constant in various ways and the result will therefore be very uniform. This labour-saving method is practical where a large quantity of film is handled regularly. Most machines, however, are as yet very expensive.

The *manual* method — by far the more common — does not entail only moving the films from one tank to another at proper intervals; it is also necessary to adjust the development time carefully in accordance with the condition of the solution, estimated empirically or by special tests, and to improve the quantity or composition of the solution as needs be, for instance, by adding suitable solutions.

The activity of a developer gradually diminishes by exhaustion, that is, its power of developing the exposed silver halide to a metallic silver image decreases. There is also a continuous loss of solution, as some of it is taken out of the tank with each film.

There are two ways to compensate for the loss of activity: the *exhaustion* system and the *replenishing* system. The first is a method in which the activity of the solution is permitted to diminish gradually and the radiographic density is maintained by a successive increase of the development time.

Up to the stage of complete development, the longer a film is left in the developing solution the greater the degree of its development. This is the basis for maintaining relatively uniform radiographic results throughout the useful life of a developing bath, by increasing the time as its activity diminishes. The level of the tank should be kept constant by adding fresh developer. Special tables have been worked out, for instance by Eastman Kodak Co., which show the increase of time necessary to compensate for reduced activity. It is important to keep a record of the number of films developed so that the development interval may

be increased at the proper stage. The number of films is only approximately correlated to the film surface when many different sizes are utilized; this, however, gives a kind of mean value of the area processed. The principle is mentioned by F. C. Martin, E. E. Smith and M. B. Hodgson (1929) and by W. E. Chamberlain and R. R. Newell (1930). A simple way of counting the processed radiographs was described in one of my papers (1952); each marking of a film with the name of a patient will produce an electric impulse in a small automatic counter.

The *replenisher* system involves the addition of a stronger solution to the original developer to compensate for loss of activity and thus to permit a practically constant developing time. For different developers there are simple instructions for the proper application of the method, which is considered to be cheaper than the exhaustion system. However, the same solution should not be used too long and, in any case, should be discarded at the end of three months because of aerial oxidation and the accumulation of gelatine, sludge and mechanical impurities which find their way into the solution.

The manual methods described are those to which the various standard developers available in the market are adapted. They are used in innumerable departments with varying results. With a proper technique, very good results can be obtained. The replenishing method seems to be preferable by making the development shorter and it is increasingly employed.

The improvement of the developers and of the methods of development is a question which especially concerns the manufacturers of photographic materials, who can adapt the technique to the material in the most suitable way.

Although it is evident that developers with a strong alkali are preferable to others as far as contrast is concerned, and that the replenishing system is superior to the exhaustion system, I consider that there are further improvements to be made if the development should completely comply with the demands of the high-voltage technique. These refer not only to the composition of the developer, but also to all other conditions connected with the procedure. It is to be expected that replenishing in particular could be made still more effective and accurate, but naturally the whole procedure will be more complicated than earlier and a greater exactitude will be necessary. As regards the modification of the technique there are many interesting aspects of the problem, which will now be dealt with.

The development of radiographs has been very much discussed in the literature. A brief survey will be given of certain works which deal with contrast problems and methods of maintaining the development time constant.

The laws of development of roentgen film were discussed by R. B. Wilsey (1925). A method of sensitometry of the roentgen film was used, and with this Wilsey studied the density curve. Contrast, fog and the influence of temperature were discussed. The activity of the developer was determined by the Watkins factor: that is, by studying the time necessary for the first appearance of the image. The development time required to produce a given degree of contrast may be expressed as a multiple of this time (A. Watkins, 1893). The factor is fairly constant for every developer and is not very much affected by exhaustion, temperature changes, etc. Chamberlain and Newell (1930) also recommended the use of the Watkins factor for determining the correct exposure time. Other principles of obtaining a good processing result throughout the life of a developer are, for instance, the increase of the development time regularly with the calendar or the number of films processed. The use of test strips of films exposed to a certain dose was also discussed. H. Boldingk (1930) used small dental test films, uniformly exposed, for testing the development. They were compared with a simple standard.

Different modifications in the regular developing technique were studied by Herz and Luft (1933). The influence of a water bath before processing, of agitation of the developer and of added illumination before or after the exposure was discussed. None of these principles gave any material improvement in the result, although agitation seemed to increase the speed of development, especially in the beginning.

In a study of the exhaustion of the developer and of practical methods of periodic regeneration, J. M. Kenny, E. A. Harvey, P. D. Woolsey and H. Baines (1937) have determined the concentration of developer constituents during exhaustion. They showed graphically that fairly small decreases in the carbonate and sulphite concentrations took place, but that the bromide showed a heavy increase in concentration. In experiments with periodic regeneration they found a way of keeping the bromide concentration constant. The bromide content was brought back to its original value at frequent intervals by removing a quantity of the partly exhausted developer and filling up with bromide-free developer. A surprising uniformity in the concentrations during a long period was demonstrated graphically. In a practical application of the method there was a striking uniformity in the control test-strips, developed once a week during a three-month period. The method was said to be by no means more expensive than the regular techniques.

An important fact pointed out by Kenny, Harvey, Woolsey and Baines is that the decrease in the developing power seems to be due to a retardation of the process by an increase of the bromide concentration; and not to any real exhaustion of the constituents.

The method of adjusting the concentration of bromides by draining off a part of the developer and filling up with the replenisher was used also by S. R. Kjellberg (1950), who pointed out the importance of making that operation in the morning, after all mechanical impurities and sludge had collected as a sediment during the night. Kjellberg used a circulation system with filters and automatic temperature control, which was described in detail 1954.

The favourable effect of replenishing with a standard developer (Agfa) was presented by H. Dehio (1938). The contrast was kept unchanged until more than 3 square meters of film had been developed in every litre of the solution.

Influence of temperature

Similarly to all chemical reactions, development shows a marked dependence on the temperature. There is, however, a different influence of variation in temperature with different kinds of developing agents (C. B. Neblette, K. Mees, and others). In a mixture of metol and hydroquinone, the most common substances in radiographic developers, the relation between these two is of importance. The order of magnitude of the variation for an ordinary routine roentgen developer is from 5 min. at 19° C (66° F) to 3 min. at 24° C (75° F).

The solutions are most effective when used within a comparatively narrow range of temperatures. At low temperatures, below 16° C (61° F) some of the chemicals are sluggish in action. Above 27° C (80° F) they work too rapidly and may produce a disturbing fogging. Such a high temperature will also soften the emulsion so that it is readily damaged. 19° C (66° F) is often recommended as an optimal value and temperatures above 21° C (70° F) should be avoided, because of the increasing tendency of fogging and swelling of the gelatine. Up to 24° C (75° F) development is still possible in ordinary solutions if some precautions are taken. Above 24° C (75° F), development may be performed with some sacrifice in radiographic quality. A hardening bath, containing, for instance, potassium chrome alum is then essential after the development. The addition to the developer of sodium sulphate (Glauber's salt) is also necessary to prevent the emulsion from swelling. The bromide content of the developer should be at least doubled to reduce fogging. For still higher temperatures, initial hardening with formalin solution is necessary.

A very important factor is the constancy of temperature conditions throughout the processing. The washing water should also be of the same temperature as the developer. Variations in temperature between the baths may cause film-faults such as frilling, blistering and reticulation.

A common misunderstanding is that the developing temperature may

be raised to a considerable degree without any special precautions. In fact, it is not advisable to use a temperature higher than 21° C (70° F). In any case, in view of the high degree of precision required for optimal processing results suited for high-voltage technique, measures must be taken to keep it *constant*. An unintentional variation of 1° may cause a change in the necessary development time of about 20 % and render a correct time control of the development quite useless. Variations in gamma value will occur and the optimal efficiency of the developer be lost.

An automatic system for keeping the temperature constant seems to be necessary for all cases in which constant optimal photographic results are required. Many patterns of thermostatically controlled heating and cooling systems are available. Relatively simple mechanical thermostatic valves for mixing hot and cold tap water have proved to give very constant and reliable results. Such valves have served very well for a long period in cinema film processing units as well as in many radiographic departments. Water of controlled temperature passes through a water jacket: this may take form of a large sink in which all tanks and solution bottles can be placed to regulate the temperature of the contents. In this way, all the baths will have the same temperature and there will be no risk of reticulation or other faults.

A further improvement is to use the same water for washing. Cold tap water in many places may have a very low temperature — in winter time, much below 10° C (50° F). The washing also depends on the temperature. From Neblette, Mees, and others, we find that temperature has some influence upon the washing. 21° C (70° F) gives about 15 % shorter washing time than 8° C (46° F). It should also be noted that the use of fixing baths containing ammonium salts will decrease both the fixing and the washing times.

Conclusions

It has been shown that changes in voltage have no influence on the density curve. On the other hand, the development technique is of fundamental importance for the shape and gradient of the curve. These factors are decisive for the rendering of contrast, which is especially important in high-voltage technique.

If developing machines are not used, the replenishing system is most suitable. Developers with strong alkalis give higher contrast, and a development time of 21° C (70° F) produces more rapid development. Changes in temperature must be eliminated and the time-control must be very accurate. Replenishing, according to the instructions of the

firms supplying the developers, is performed very simply. A still better result, however, might be obtained if a more complicated system were used, including reduction of the bromide-rich content by draining off the solution and at the same time adding a bromide-free replenisher. At present, there are no commercial developers available which are suited for such a method. There are as yet no facilities for the simple, rapid and exact checking of the developing activity: an important factor for the control of replenishing. One may hope and expect that the manufacturers of film and developers will concentrate on remedying this defect.

INTENSIFYING SCREENS. PROBLEMS AND DEVELOPMENTS

A survey will now be given of the problems associated with intensifying screens. A historical review of the literature will first be presented as a background to the discussion of new types of screens, particularly those coated with barium lead sulphate — the so-called 'high-voltage screens'.

A historical review of the screen problems

As early as 1897, screens were used to increase the photographic effect of roentgen radiation. It was then considered that calcium tungstate was the most suitable material (L. Levy and D. W. West 1933). Of the different possible chemical substances, this material seems to have been considered the best and has been in continuous use during the subsequent development, whereas for fluoroscopic screens cadmium zinc sulphide, which emitted visible light of a spectral composition more suitable for the eye, was employed.

R. B. Wilsey (1924) discussed the intensifying factor of radiographic screens and pointed out that tests must be made with a phantom under normal conditions of radiography, since unfiltered radiation produces different values. In order to secure identical exposure, a sector wheel of a type similar to those used in ordinary photographic sensitometry (L. A. Jones, 1934, T. H. James and G. C. Higgins, 1949) was used. Wilsey stressed the importance of perfect contact between the screen and the photographic material.

In 1926, the screen problem was discussed by F. Peltasson who considered, among other questions, the effect of halation, which was particularly marked with the photographic glass plates used at that time and which was dependent on the character of the screen support.

F. E. Swindells (1927) studied some physical properties of intensifying screens and emphasized that the density curve was favourably affected by screens with an improved contrast, especially in the lower densities. In 1928, Swindells discussed further the physical properties of fluorescent screens. He considered that calcium tungstate is by far the most suitable chemical for screens. The fluorescence is in the spectral region of 3,800—4,200 Å, where the films have a high colour sensitivity. They thus possess a suitable actinic power. Lag or after-glow was also

discussed; it is proportional to the light intensity up to a certain borderline value. In agreement with WILSEY, SWINDELLS (1930) pointed out the influence of the quality of the radiation on the intensifying factor, the ratio of two exposures being required to produce the same density, one being made with and the other without screens. At higher radiation energies, the intensifying factor will be higher. The properties of the screens vary with the makes, possibly depending on differences in the physical condition of the fluorescent substance.

J. H. HARTMANN (1931) presented a most detailed account of the value and the properties of intensifying foils, mentioning also after-glow. The intensifying factor, as well as the degree of density, is dependent on the appearance of the crystalline substance. HARTMANN considered the possibility of using a substance mixed with a stain that gives less halation and thus improved sharpness. H. CHANTRAINE (1932) presented a detailed description of a screen of this type which was called 'Rubra'. A very good result was obtained with this screen which despite fairly heavy colouring merely doubled the exposure. The definition was said to be of the order of magnitude of 0.1 mm.

H. FRANKE (1932) discussed the influence of intensifying screens on the contrast of roentgenologic images, and J. BARÓN in the same year described a simple method of determining the time of after-glow of fluorescent screens using the intermittent flow of radiation from the tube. If a rapid movement of a body seen against the illuminated screen appears to be interrupted because of the separate light maxima, the after-glow (lag) must be considerably shorter than the difference in time between two light maxima, that is, less than 1/100 second, at 50 cycles AC.

CHANTRAINE (1933) discussed the loss in definition with intensifying screens. He tested the screens by a special method called 'Schwächungsverfahren', by which it is possible to assess the visibility of a detail numerically. A tissue-like structure was superimposed during the tests to ensure conditions similar to those in radiography. CHANTRAINE considered that screens are of great value as regards increased contrast which gives improved visibility of detail. The lower limit for the size of detail visible with screens was drawn at 0.4 mm.

LEVY and WEST (1933) and N. S. FINZI (1933) described a new substance for screen material, zinc sulphide ('fluorazure') which gave a high emission of light and in which the low atomic weight of the substance contributed to a decreased absorption in the front screen. The substance employed seemed to be easily obtainable in purified form. L. LEVY, D. W. WEST, H. A. EDGERTON, and R. B. BROCK (1934) discussed the after-glow and the latent phosphorescence from the 'fluorazure' intensifying screens. These phenomena were fairly marked and disturbing. Red light was said to affect the after-glow. The opinion about the said screens may

be described as negative, and they are considered to have several disadvantages which do not obtain with the calcium tungstate screens.

H. Steps (1935) carried out a detailed investigation of the spectral distribution of light from screens, using a photometer with different filters, and also studied the definition. H. Klug (1935, 1937) made a close comparison between different makes of fluoroscopic screens and presented the results graphically. For assessing the definition of details, a method similar to Chantraine's was used. It aimed at establishing the smallest visible difference in light that can be discerned. The tests were made with material then available on the market and are of no actual interest at the present time.

K. Juris and G. Rudinger (1937) devised a method for directly measuring the resolving power of intensifying screens without the use of a microphotometer. They used a perforated plate with small closely placed apertures. The density produced by halation, which is correlated to the definition, could be measured separately.

The appearance of phosphorescence, that is, emission of light independent of irradiation, was discussed by Wagner (1938) and by Ortmann and P. M. Wolf (1938). Mechanical action such as pressure on sulphide screens, used for fluoroscopy, may sometimes produce light phenomena. These are not noticeable with calcium tungstate screens.

Juris and Rudinger (1938) examined different types of screens for graininess, and found that a screen with dye in the crystal substance was superior and gave a practically grain-free impression to the eye. The authors discussed the reason why the graininess was apparent when both the silver grains (about 0.001 mm in size) and the calcium tungstate crystals (about 0.01 mm in size) are below the generally accepted limit of visibility for the naked eye, which in their work was drawn at 0.05 mm. It was considered to be explained by the grouping of the grains and by the fact that these are apparent to a higher degree when there are two layers of emulsion.

G. Spiegler and G. Rudinger (1938) carried out microdensitometric studies of films with pictures of narrow slits. Because of halation, the picture will spread out laterally, and with very small objects a lower contrast be obtained. These facts seem to be of interest in the radiography of small vessels. K. C. Clark, G. R. M. Cordiner and P. Ellman (1941) tested screens with simultaneous control by non-screen radiography. B. Stanford (1941) suggested optimal combinations between films and screens of makes available at that time.

Stanford, in another communication of 1941, discussed a very interesting and apparently useful fact, namely, the effect of varying the coating thickness of the fluorescent material of a screen on the luminous

output obtained. The amount of light emitted from the screen seems to be directly correlated to the thickness of the layer.

H. S. Tasker, in 1945, made a thorough study of the properties of different kinds of screens. Investigations on the more important properties of current screens both for medical and industrial radiography were described. He pointed out that calcium tungstate appears to belong to the small class of luminiscent materials that are active in the chemically pure state. The practical application of zinc sulphide ('fluorazure') to radiographic screens, however, is rendered possible only by the addition of minute amounts of silver as an activator, and nickel as an afterglow 'killer'.

The most detailed and up-to-date accounts of the properties of screens were presented by R. H. Morgan (1945, 1946, 1947 and 1949), and W. W. v. Allen and Morgan (1946, 1949). On the whole, their results are probably still of general applicability. Of the details discussed in these works a few only will be reviewed.

Morgan studied the characteristics of different films and screens. The ability to record details is measured by determining the finest linear pattern which can be resolved by the film-screen combination. While Morgan found that the resolving power declines as the wavelength of the radiation decreases, Morgan and Allen maintained that it is independent of the wavelength. The discrepancy may probably be explained by the fact that the silver wire-mesh used by Morgan as a test object was not entirely radiopaque. Morgan and Allen used a slit mechanism in measuring the resolving power of screens. The width of the slits could be adjusted by screws. They found a striking similarity in resolving power, not only between screens of different makes, but also between screens of the same manufacturer rated as 'high definition', 'medium speed' and 'high speed'. The resolving power of the more 'coarse-grained' screens is not appreciably low, and a significantly higher resolving power than that of the average screen is very rare.

With their test apparatus, Morgan and Allen found that at densities ranging from 0.5 to 2.0 the maximum resolving power is obtained at minimum exposure contrasts at a density of 1.1. Therefore, if because of the nature of the material under examination the exposure contrast is very low, the greatest resolution and the optimal radiographic result will be obtained at densities of about 1.0. These facts should, in my opinion, be borne in mind, especially in using the high-voltage technique which gives a very low exposure contrast.

Several factors apart from the screens, such as penumbral unsharpness and blur due to movement, affect resolving power. Contrary to earlier opinions, the sum of the factors causing unsharpness does not correspond to the actual definition, but, according to Morgan, to the

highest value of the inherent factors; if these are equal, it lies slightly above them.

K. Hansleuter (1949) tested a series of the more rapid screens and found throughout that an American pattern, the 'Patterson High Speed', was superior as regards speed, especially at high voltages. Tests were made up to 90 kV. Levy and West (1950) published an account of various screens. They verified the considerable increase in speed that had occurred during a period of 20 years. They also briefly discussed metal screens which principally function by emitting secondary electrons under high-energy roentgen ray excitation.

A. Frantzell, in 1951, in his great work on soft-tissue radiography, also discussed the question of screens. He considered the grain size of screen coatings to be of less importance to the resolving power, but pointed out that the properties of the photographic emulsion were a more important factor in this respect.

H. Schober and C. Klett (1953) carried out detailed analyses of screens available on the market with photomicrographs. They drew the conclusions that the cause of unsharpness is not to be found in the size of the crystals but, in all probability, in the thickness of the crystal layer, in the nature of the substance in which they are embedded, as well as in the nature of the support.

Because of their small size the individual crystals in the layer cannot affect the sharpness at all; in some cases the groups of crystals may do so, but the previously mentioned factors are those which primarily affect sharpness. Thus, the thicker the layer, the greater the halation effect and the poorer the sharpness. At the same time, there is a distinct relationship between the thickness of the layer and the emission of light from the screens. Rapid screens must therefore always have low resolving power.

In my opinion, Schober and Klett's investigation is, in certain respects, of fundamental value. Although Stanford studied similar problems earlier (1941), this recent work has thrown considerable light on these important questions.

A study of the output of light from screens was published in 1954 by W. Frommhold. According to his observations, an increase in voltage above 140 kV should not give any considerable gain in luminous output from calcium tungstate screens. This gives a more unfavourable view of the conditions at higher voltages than the present photographic investigation. Frommhold made his measurements with the aid of a secondary electron multiplier. It is, however, to be expected that a difference in the results will be obtained as the technique is very remote from the ordinary photographic one. The effect of secondary electrons from the screens and of secondary radiation is excluded. These, however, may have a certain practical importance.

A new type of screen

Since about 1950, a new kind of fluorescent substance has been in use in medical radiography, *barium lead sulphate*. This compound, which up to the present has not been much known in this connection, has been found to possess interesting properties that are of value in radiography at high voltages.

The introduction of barium lead sulphate, which was made in 1942, is an interesting development. It is a new fluorescent compound and as regards its preparation it is peculiar insomuch as it can be precipitated in an active form, no firing operation being necessary. The crystal structure will therefore be very suitable. I should like to refer to British Patent 540,252 by F. F. Renwick and H. S. Tasker (1940) covering the preparation process. The exact chemical composition of the isomorphous mixture is not critical: however, the best results, according to Tasker (1945), are obtained with five to twenty per cent by weight of lead sulphate. The new material seems to have been used at first for the fluorescent undercoat of *Kryptoscreen X-ray paper* and in screen form as *Brytex Leaves*. Since the compounds used in these materials were very fine-grained, a result of the special preparation process, the active layer could be made very thin and the loss of sharpness was very small. The intensification, however, was relatively low compared with other salt screens. The speed of *Brytex Leaves* relative to the ordinary calcium tungstate screen was, according to Tasker, 50 %, which could partly be explained by the low coating weight employed.

The application of barium lead sulphate mentioned refers to industrial use. In medical radiography the new compound has not been of actual interest until its recent application in connection with the high voltage technique. The substance has thus been used by different manufacturing firms for the production of special screens. There is, however, a difference in character between the barium lead sulphate of these screens and that of the earlier products, the *Brytex Leaves*. These new screens have a coating thickness and grain size comparable with the coarsest ordinary screens and are in no way superior as regards definition. According to information obtained in England, Levy and West originally produced the substance in Manchester and it was subsequently used by Kodak, Ilford, and other firms. As far as I know, the two firms mentioned were the first to manufacture special medical high-voltage screens with barium lead sulphate which they called *Kodak 80* and *Ilford HV*, respectively. These types of screens may be regarded as relatively new, and up to the present have not been used to any noteworthy

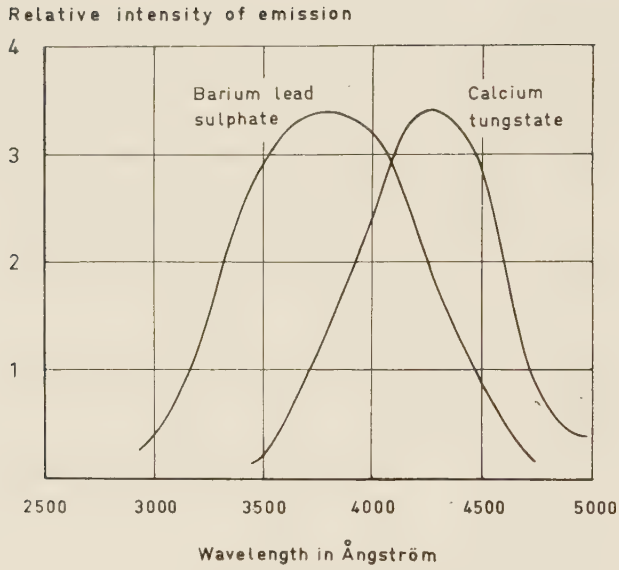


Fig. 30. Spectral distribution of light emission from barium lead sulphate and calcium tungstate screens. Diagram redrawn from Eastman Kodak Co.

extent. It should be pointed out that Patterson, earlier than these firms, is reported to have used barium lead sulphate in a high-speed screen which, however, is not described as being exclusively suitable for high voltages. References should be made to HANSLEUTER's previously mentioned comparison between different screens, one of which was found to be especially suitable as regards speed at high voltages. This screen was very probably made of barium lead sulphate.

I have had an opportunity of carrying out some comparative tests with the new type of screens, and an account of this work will now be given.

A comparison with a calcium tungstate screen as regards the visible colour of the fluorescence showed that while the calcium tungstate gave a brilliant light blue fluorescence, the barium lead sulphate produced one which was a dark deep blue; the latter appeared considerably weaker, because of the fact that all the actinic radiation cannot be perceived by the eye. In fact, one of the characteristic properties of barium lead sulphate is that it fluoresces to a great extent in the ultraviolet region. References should be made to Fig. 30 after Eastman Kodak Co, where the relative intensity of emission in different spectral regions is shown. The high sensitivity of the photographic material in the very short-wave part of the visible spectrum and in the adjacent ultraviolet region contributes to the very good photographic result obtained with these screens.

Sensitometric tests were made in which a barium lead sulphate screen was used concomitantly with a calcium tungstate screen of average sensitivity and resolving power. The roentgen film used was of the same kind as that employed in the tests previously described, being representative of makes available at the present time. The photographic technique applied was in every respect the same as the one previously described in detail. The roentgen apparatus as well as the other conditions were also the same, everything corresponding to alternative 1 in Fig. 2 on page 26. A wax phantom, 16 cm in thickness, was used, giving an absorption of an order of magnitude corresponding to that of a human part, for instance, the abdomen. The two screens in the form of pieces of suitable size, were placed in the same cassette which, for the sake of comparison, also contained a so-called 'lead screen'.

Since reciprocity law failures may be expected at the radiation emitted by the screens, special measures must be taken to reduce this effect. References should be made to the works of R. H. Morgan (1944) and A. Frantzell (1950) in which these problems are discussed. The latter author showed to what extent these factors are involved in certain radiographic problems, *e. g.* in testing two different emulsions. In the present test, the exposure time was therefore, when possible, kept constant at the same value for each series of tests, and the intensity varied with distance and milliamperage. With the apparatus available the latter could be altered within very wide limits.

Density curves were made for three different kilovoltages, 50, 100, and 180 kV, for the respective screens, in series with logarithmically varied exposures. At the intermediate kV values, simple exposures were made. Through preliminary exposures all these could be adjusted so that the densities would have the value of about 1.0. All the films were then developed under constant conditions (cf. page 24), and as has been mentioned earlier, the density values were measured in a densitometer with a photoelectric tube.

From the test films, the different densities were read and the intensities required for a certain density, *e. g.* 1.0, at different kilovoltages, calculated through the respective density curves.

Fig. 31 shows a curve demonstrating the relative exposures required for the barium lead sulphate screen and the calcium tungstate screen to produce the same density ($D = 1.0$). At 40 kV, the same exposure is necessary. The heavy material of the barium lead sulphate screen absorbs that much of this low energy radiation. A steady increase in efficiency is noticeable up to about 110 kV after which the difference in the exposure required decreases. At 110 kV, about 60 per cent, and at 180 kV about 80 per cent of the exposure of an ordinary screen is re-

Exposure required with barium lead sulphate screens relative to calcium tungstate screens

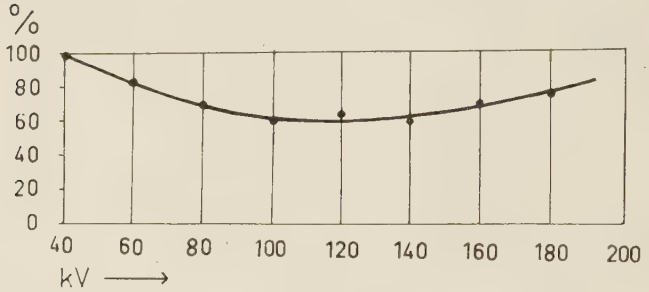


Fig. 31. Relative exposure required to produce the same density (D = 1.0) for barium lead sulphate and calcium tungstate screens.

quired. The maximum gain would probably be between 110 kV and 120 kV.

Curves showing the mAs required for a density of 1.0 for both kinds of screens have been given in a previous section. Reference is made to Fig. 5 in which the dotted curve represents the calcium tungstate screen, and the unbroken lower curve the new barium lead sulphate screen. The problems of film dose have already been discussed.

As has been mentioned earlier, the radiographic intensity of the radiation at different kilovoltages has often been correlated to a certain power of the kV value. For the barium lead sulphate screen used in the present experiment, a suitable power in the range 110 to 140 kV would be 2.8. Between 140 and 170 kV, the suitable power seems to be about 2.1.

In order to obtain some idea of the resolving power of this new type of screen, a number of fine metal wires of stainless steel with diameters down to 0.1 mm were photographed simultaneously with the sensitometric tests. The wires were placed in close contact with the cassette so that geometrical unsharpness could be practically eliminated. These tests, which were not carried out for the purpose of obtaining a mathematical expression of the sharpness registered but rather a subjective impression, showed a striking difference in the richness of picture detail compared with the ordinary screen. The grain size seems to be larger in the barium lead sulphate screens, and, further, the groups of grains appear to be more heterogeneous. There is also marked scattering, that is, single details are surrounded by an unsharp transition zone. The impression is given that the crystal in the new type of screen is more translucent. The difference in sharpness will be seen in Fig. 32, in which some details of the wire images are shown.

As could be expected, the resolving power is thus entirely different.

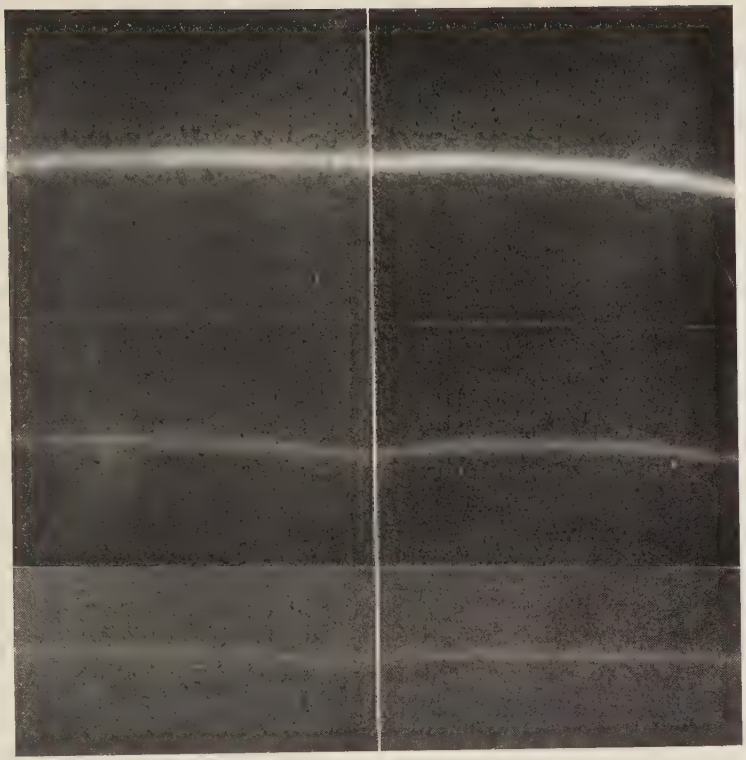


Fig. 32. Small metal wires depicted with the barium lead sulphate screen and an ordinary calcium tungstate screen, respectively. Note the considerable difference in definition. 7.5 ×.

The barium lead sulphate screens available on the market are introduced as specially rapid screens for high-voltage technique, with a sensitivity that is superior to that of the most rapid of the earlier screens, without giving poorer definition than these. They are intended for special purposes and the resolving power is not primarily considered. A reduction of the thickness of the barium lead sulphate screen layer would naturally ensure better definition, but at the same time the speed would be partly lost. Screens of the type examined are at present the only ones available.

One of the advantages of the high-voltage technique is the possibility of employing small focal spots; these give higher definition and make up for the low contrast. It does not seem advisable to sacrifice good sharpness in order to reduce the exposure by some 10 per cent. With the demands on resolving power produced by the new angiographic technique, screens with inferior definition are of no value. As seen from tests de-

scribed earlier, such a slight profit as that of the magnitude mentioned above may be readily obtained by using a slightly higher voltage. Another means of reducing the exposure time, if required, is to shorten the focus-to-film distance. The exposure time may be reduced by about 15 per cent merely by shortening this distance from 80 to 75 cm.

A new support

In the past few years screens with a base of plastic material have been used. Earlier, no special attention was paid to the character of the support. Cardboard was almost exclusively used, but with the increasing usefulness of plastics for all purposes, it is not surprising that these are also being utilized in this field. I have had the opportunity of studying screens of plastic material, and shall present certain considerations, since different opinions have been expressed concerning these screens, and since the problems are bound up with a subsequent discussion on cassettes and pressure pads.

The plastic material that has been used is completely translucent. In the screen concerned, the *Kruppa Plastix*, the fluorescence was observed, on irradiation, from both sides at practically the same strength. The plastic materials are characterized by their high transmissibility to light and have also been used as light conductors. It would be readily suspected that halation would occur more easily from, for instance, intensely irradiated areas to surrounding parts. In a series of comparative tests with degrees of density and contrasts of a magnitude usual in radiographic work, no disturbing effect of halation was noticed, however. In these tests, as in the earlier ones, fine metal wires were used. No difference in quality of the image visible to the eye was found on comparison between corresponding types of test screen and ordinary screen with a cardboard base. Any effect of the base in this respect may evidently be ruled out. On the other hand, I have on some occasions found that personnel accustomed to cardboard base screens, because of the smooth back of the plastic screens when mounting them into the cassettes, will turn them back to front. Since the support is translucent, an image is still obtained, although it is less sharp and the detail poor, because of halation. With the new screens, the surface that has to be in contact with the film is matt, contrary to what is usually the case.

A property of some plastic materials, which is considered to be of some importance in their use as screen supports, is the discoloration that occurs with prolonged irradiation. It is believed to be caused by purely chemical changes in the material due to the effect of radiation and gives a reduced transmissibility. As regards the base material as such, this

discoloration should be of no significance whatsoever. A factor of greater importance is probably the change in the binder that holds the crystals together, by which a lowered transmissibility to light may reduce the effect of the screen. Tests were made to find out whether there was any noticeable reduction in the fluorescence in screens heavily exposed for a long period in comparison with those kept in the dark without radiation. Some small pieces of screens were placed in a tube hood behind the primary diaphragm cone in such a way that they did not affect the primary beam but were exposed to radiation at each exposure. The distance from the focus was only 6 to 8 cm. With the tube used, belonging to a urological table, a minimum of 50 exposures per day was made. The fragments were left in the tube for 18 months and were probably exposed to a radiation dose corresponding to several tens of thousands of roentgen units. The test pieces together with non-irradiated screens were then placed in a cassette with a roentgen film and exposed. At the usual density levels there was no difference in density between the image obtained with the non-irradiated screen and that obtained with the intensely irradiated portions of screen. The result is interesting in that it also shows that generally no ageing of the fluorescent substance itself by the effect of radiation need be taken into account, at least not so far as calcium tungstate is concerned.

One difficulty encountered in using plastic screens of the design available up to the present is in the flattening. There is some stress in the plastic material, either being present from the beginning or appearing some time after the screen has been manufactured. Because of this stress it is very difficult to ensure plane surfaces, the corners in particular causing considerable trouble.

In some types of plastic screens a thin layer of foam-like plastic is attached as an extra pressure material in front of the front screen. This layer may have been devised to overcome the difficulty of ensuring even contact by pressure. This arrangement is not successful from the point of view of secondary radiation, for reasons stated later on. The greatest disadvantage, however, is the fact that the porosity of the material will sometimes be visible in the roentgenogram, as was found in special tests. The superimposing of such a foam-like structure is a disadvantage in the study of all fine image detail, for instance in angiography.

Screens of plastic material have, in some respects, an unquestionable advantage. They are flexible and are therefore suitable for special work where curved cassettes are required. As has been pointed out by R. D. Leonard and A. W. Georg (1932), curved cassettes are sometimes of considerable value in obtaining unconventional views of various parts of the body, for instance, in the study of fractures of the femoral neck. In operative cases, soft flexible cassettes may also be required. O. Ols-

son (1949) described a flexible rubber cassette with screens for the radiographic examination of operatively exposed kidneys. Tests with a flexible plastic cassette, 13 × 18 cm, designed by the present writer showed that any desired curves were readily obtainable. Flattening is sometimes more easily performed when the cassette is curved. The surfaces of the screens tested, however, were found to be much more susceptible to mechanical action, such as friction, which cannot be avoided with flexible cassettes. On the other hand, the screens appear to be highly resistant to the action of water and chemicals.

Metal screens

The characteristics of metal screens and their properties have been discussed by, for instance, Tasker (1945). He pointed out that H. E. Seemann (1938), in the examination of different metals, found that those towards the end of the periodic table are the most suitable. Lead is generally chosen because of its cheapness and ductility which enables it to be rolled to any desired thickness. A small percentage of antimony, however, is added to give a more durable product.

Metal screens are usually supplied and used as a pair in the same way as ordinary salt screens. The lead foil of the front screen is approximately 0.004 in. thick while that of the back screen is about 0.006 in. (0.10 mm and 0.15 mm, respectively). For further information the reader is referred to the Kodak Data Book.

The effect of the lead screens in contact with the film during exposure may be summarized as follows:

Firstly, they have an intensifying action on the radiographic image, which is due mainly to the emission of electrons from the lead under excitation of the radiation and, to a smaller extent, to the emission of secondary roentgen rays. This intensification is greater the shorter the wavelength of the radiation, a feature of particular value in radiography with very high voltage roentgen rays, *e. g.* 1,000 kV and gamma rays. The absorption of the front screen diminishes the intensifying effect for lower energy radiations, and below for instance 140 kV no intensifying effect may be expected. At 200 kV, however, in the radiography of steel, lead screens permit an exposure of about one third of that necessary without screens. Because the object is steel, the radiation reaching the film must be heavily filtered and of quite another character than with medical objects.

Secondly, lead screens greatly reduce the photographic effects of scattered radiation. This longer wavelength radiation will be absorbed more, and intensified less, by the screens than the primary radiation, the result being greater contrast and clarity in the radiographic image. I should here like to refer to the fact that metal foils have been used and

discussed as purely secondary filters by H. Laurell (1932), K. Lindblom (1934), and others; in these cases, however, they were not used in real contact with the film. An important fact is that the secondary radiation ordinarily passes through the foil in an oblique direction, in contradistinction to the primary radiation, which penetrates it perpendicularly, or the shortest way. The secondary radiation thus has a longer distance to travel through the lead and will be more absorbed.

As regards definition, there is no perceptible loss in sharpness and, with properly prepared screens, no graininess.

In the present studies, the lead screens have also been examined at different kilovoltages. These tests concern the intensifying effect and no other properties; in them the same wax phantom — 16 cm in thickness — as in the other screen tests was used and there was no grid.

The test films — ordinary films designed for screens — were inserted between a pair of lead screens. A part of each film was directly irradiated.

The tests made with kilovoltages up to 180 showed that in no case was there any intensification and the front screen acted only as an absorbing medium. The difference between blackenings obtained with and without the screens, however, was continuously reduced with higher voltages.

We may conclude from this that lead screens in connection with medical radiography are of no importance as intensifying media up to the region of 180 kV. This may be explained by the fact that the radiation employed in medical radiology is of quite a different character from that used in industrial radiology. One inch of steel, for instance, gives very heavy filtration compared with the human body. The radiation will be of another quality and many soft primary rays of photographic value present with the human objects will be lost in the front screen. The value of lead foils as filters of secondary radiation, however, may justify their use for this very reason. Lead screens have often been used in industrial radiography simply for their filtration effect. In that case, the lead foil may be placed between the front screen and the face of the cassette.

Conclusions

The progress in the field of screen work has led to the predominating use of calcium tungstate screens. Parallel with this material a new fluorescent material, barium lead sulphate, has recently been introduced and is now being used in roentgen diagnosis. It is characterized by fluorescence in new actinic spectral regions previously of no practical interest. The same radiographic effect is obtained with shorter exposure, which is a remarkable advantage, most marked at high voltages. The best result

is obtained at 110 to 120 kV. The screens manufactured so far are designed with a view to speed and with less consideration given to the grain. Their resolving power is considerably lower than that of ordinary screens, and they seem to be less suitable in the type of radiography where good sharpness is essential, for instance, in angiography. Considering the fact that the use of high voltages considerably increases the radiographic effect of radiation, the advantage of barium lead sulphate screens does not seem to be of much value, especially since the quality of the image is jeopardized. The usefulness of the new screens is thus entirely dependent on the requirements associated with each radiographic purpose.

The new material in the base of the screens, so far as the types available at present are concerned, seems to have a disadvantage associated with the physical properties of the material. Stresses appearing in the material render flattening difficult and constitute a possible source of unsharpness. Other disadvantages, suspected because of the nature of the material, were, by various tests, found to be of no importance.

Lead screens seem to be of no value for intensifying purposes in medical radiography at least up to the region of 180 kV. They may, however, be useful as secondary screens. It is then preferable to use them together with ordinary screens.

CROSS-GRIDS, GRID MOTION AND VISIBLE PATTERN

There is no reason to doubt the general opinion, also supported by literary references, that high-voltage technique should require more from the grids and that cross-grids should be superior.

An exhaustive study of grids with regard to their construction for maximum efficiency at different voltages seems to be of particular interest. At present, however, such a study is difficult, perhaps impossible. as all extremes in grid element dimensions, which are necessary for a comprehensive study, have not been obtainable from the manufacturers.

Besides the problems of grid efficiency there exist others of great importance, which refer more directly to the quality of the radiographic picture as seen by the eye. Since cross-grids appear to be the better proposition and are becoming more widely used, the problem of visible grid structure has come into the foreground, for these grids have practically always been stationary.

Elimination of grid structure seems to be essential and I have concentrated on the problem of producing a radiograph completely without superimposed pattern — that is the problem of motion of the cross-grid.

Before I take up a discussion of the motion of cross-grids I will define some fundamental concepts and give a review of the literature dealing with cross-grids and grid problems in general.

Finally I will discuss stroboscopic effects in grids which also are a frequent cause of visible structure in the radiograph.

SOME FUNDAMENTAL CONCEPTS

It seems appropriate to discuss more closely the general principles of construction of modern parallel grids. They consist of plates composed of transversal thin members — slats — of absorbing metal (lead) which are separated by materials with low absorption, such as fibre, wood, cardboard, plastic, or aluminium. A strong bonding material or a thin coat of solder holds this assembly together. A cross section of a modern grid is shown in Fig. 33.

Certain characteristics are important for the evaluation of the qualities of a grid, and for the comparison of different grids. A grid should offer a minimum of resistance to the primary radiation from the focus,

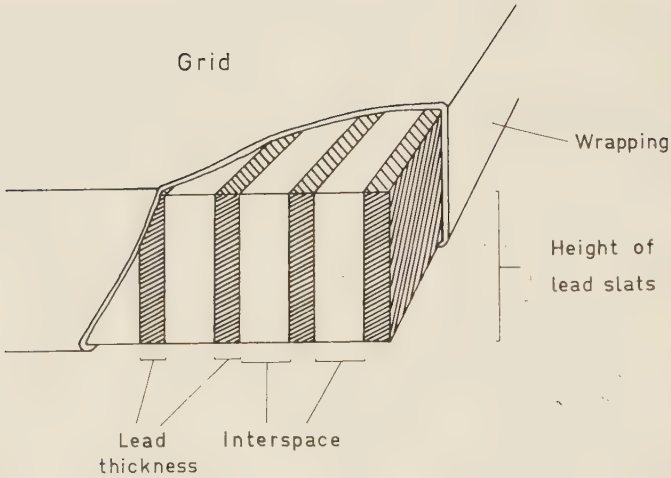


Fig. 33. The composition of a modern grid. The lead slats are separated by aluminium, fibre, or plastic which fills up the interspace. The grid is frequently wrapped in aluminium (wrapping partly removed). The characteristic dimensions are shown. This grid is uncentered.

which produces the image, while diffuse secondary radiation should be checked. The term *ratio*, which is a kind of direct measure of the filtration of secondary radiation, refers to the radioparent interspaces between the radiopaque slats of the grid. If the height of the interspaces in relation to their width is increased, it is evident that the filtration of secondary radiation will be more effective. The *ratio* signifies the relation between slat height and interspace (Fig. 33). Existing values vary between approximately 4 to 1 and as much as 20 to 1 or even more. For very low values, the influence of divergence in the beam of rays may be neglected, and the slats need not be inclined. In this case the strips are lower and the grid thinner in its peripheral regions.

Centering will often be necessary to bring the whole set of slats in parallel with the diverging incident rays. The centering is adapted for certain working distances, such as 80, 90 or 100 cm, but for low-ratio grids there is a fairly wide tolerance as regards the distance practically possible. A high ratio always requires a considerable degree of accuracy as regards the positioning of the tube. The process by which the slats are given their inclined adjustment is slow and exacting. Nowadays, flat grids are practically the rule, but in earlier practice curved surfaces corresponding with the centering were also employed.

These two concepts, ratio and centering distance, are generally known, but other characteristics have attracted very little attention. Only rarely are the thickness of the radiopaque strips, and their interspaces,

or the relation between these factors discussed. These figures, however, are valuable as additional characteristics of the grid.

If we assume that the grid consists of perfectly radioparent and perfectly radiopaque elements, the proportion between these elements will determine the total radioparency of the grid. An increased lead thickness may then be balanced by a wider interval between the strips, and the ratio is maintained by increasing the strip height. In practice the middle course will usually be the answer, on account of the techniques used and of the desired spacing and thickness of the grid.

It will be shown that the proportion between interspace and slat width is of very great importance in connection with the movement of a cross-grid system. It seems of value to quote this relation as an additional characteristic of the grid. Apart from an indication of the radiopacity, this ratio affords information which, as will be demonstrated later, is necessary for the evaluation of suitable directions of movement for the elimination of parallel stripes with cross-grid systems. Reference should be made to the chapters which follow. The expression *interspace factor* is proposed for this relation. For one identical value of the interspace factor, there may be arbitrary dimensions of slat and interspace, but their mutual relation remains unchanged. The scale may vary, but the general pattern remains the same. Furthermore, if *lead thickness* is introduced as a characteristic of the grid, it will be easy to calculate the interspace from the interspace factor.

All qualities and dimensions of a grid are obtainable from the following characteristic data, which have been arranged according to their relative practical importance.

Ratio (Slat height/Interspace)
Lead thickness
Interspace factor (Interspace/Lead thickness)

Centering distance

Of these factors, the first three are closely correlated. The fourth, centering distance, is placed apart, having no immediate connection with the other characteristics.

Let us assume a single parallel grid with a ratio of 10 to 1, lead thickness 0.05 mm, and interspace factor 5. The centering distance is arbitrary. From the lead thickness and interspace factor we obtain the interpace (x) between the slats, which is $\frac{x}{0.05} = 5$; $x = 0.25$ mm.

The value for the interspace between the slats as obtained above may be used for the determination of the thickness of the grid (y), *i. e.* the height of the slats, if the grid ratio is known. The thickness in this case will be $\frac{y}{0.25} = \frac{10}{1}$; $y = 2.5$ mm.

All data of importance may be reconstructed in this manner.

It would be of great value, in the author's opinion, if grid manufacturers would mark their products with these simple characteristics as guidance for the radiologist interested. The ever increasing demands on grids in high-voltage radiography are a heavy argument in favour of information of quality in figures; and this seems to be of more importance than general labels such as 'high-voltage grid' etc., which signify practically nothing. Objective information of this type would permit direct correlation of the radiographic results obtained with various grid characteristics. When buying new equipment the radiologist would have a positive guarantee of acquiring the right types of grids, which he has previously found to be suitable for a certain technique.

Cross-grids are composed of two single systems of the type described, usually with the slats in two planes at right angles to each other. This arrangement constitutes a considerable improvement in the filtration of secondary radiation, which in single grids is bound to be less effective for directions of radiation which approach the plane of the slats. A low ratio will then be sufficient for the individual systems, with consequent advantages. In determining the suitable grid movement for the reduction of strips, the interspace factor is of predominating importance.

THE HISTORY AND PROGRESS OF SECONDARY SCREENING WITH SPECIAL REGARD TO THE CROSS-GRID PRINCIPLE

The progress made in eliminating secondary radiation is most fascinating, and will be concisely dealt with here. Among other things it is rather interesting to find how often grid systems with crossed components have been given attention, and how they seem to have occupied many research workers on various occasions.

The earliest apparatus designed to reduce the picture-destroying effects of secondary radiation originated from H. Albers-Schönberg. At the beginning of this century, he described tubular devices, serving not only as diaphragms for the primary beam of rays, but also ensuring compression for obtaining a considerable improvement of contrast in the photographic plate. A patent application for such a construction was made on April 2, 1902.

A system with both primary and secondary diaphragming was introduced by O. Pasche (1903). He seems to have been a pioneer in the reduction of the influence of secondary radiation by using a fairly complicated device consisting of metal plates with parallel narrow slits, the whole forming a kind of grid. Two plates moved during the exposure, one between the tube and the patient and the other between the patient and the plate. The speeds were proportioned in such a way that small beams irradiated the plate continuously during the exposure. The construction described by Pasche may be considered to have opened new ground and given an impulse to future grid constructions.

The principle of using synchronized slit diaphragms in front of, and behind, the patient in the way described was later further developed by L. G. Cole and discussed by R. B. Wilsey (1921), F. A. Wahl (1931) and W. J. Oosterkamp (1946). H. Laurell in a paper of 1932 emphasized the precedence of Pasche as far as the principle was concerned, and stated that he himself had been developing it about 1922.

G. Bucky, in 1912, reported favourable results in fluoroscopy, obtained by introducing a tube between the object and the fluoroscopic screen, whereby a certain screening and distance effect was produced. A little later Bucky (1913), discussed a corresponding principle in con-

nection with radiography; in place of a simple tube, he employed a system of metal strips placed on edge and arranged so as to correspond to a large number of tubes of quadrangular cross-section. This system was projected upon the plate as a pattern of squares. Bucky apparently found this type of cross-grid disturbing to the radiographic result, and he reported that he was trying to eliminate the projection of the disturbing pattern. There is, however, no subsequent information from Bucky on this problem in the radiographic literature. In a patent applied for by Bucky in 1915, a cross-grid situated between the patient and the photographic plate was dealt with. A principle of movement mentioned is of particular interest. Every point of the grid will describe a circular path since the diaphragm is supported eccentrically on wheels which move during the exposure. Other ideas were also touched upon in this very comprehensive patent, but it is not made clear whether freedom from pattern in the photographic plate was really obtained.

It is quite obvious how crucial the problem of the cross-grid members and their picture-destroying effects was in this early stage of development. The reduction of scattered rays by grids was apparently really made in the beginning with cross-member systems, although, as we shall find, they had to be abandoned owing to the fact that the problem of their motion could not be controlled.

In 1917, A. Lotzin published a description of a cross-grid, the elements of which were nearly of the same size as the systems now in use. Lotzin used metal strips mounted close together with an interval of only 1 millimetre, in frames placed so as to cross each other at right angles. Accurate centering of the system was possible, *i. e.* the strips were mounted in such a way as to be parallel in every direction with the beam diverging from the tube. The arrangement gives the impression of being quite modern, particularly since the grid performed an oscillating diagonal travel. As the movement of the grid was reversed, the tube current was interrupted so that the exposure was made only while the grid was moving. A parallel streakiness produced by the diagonal travel was reduced by Lotzin by moving the grid also at right angles to the direction of travel, one step at a time between each movement. Seen in the perspective of recent progress, this design must be regarded as remarkably advanced and well-planned, and its resemblance to modern arrangements is obvious. On the whole, Lotzin seems to have had a remarkably clear conception of the problems connected with cross-grids.

The results obtained with Lotzin's apparatus were very satisfactory. Nevertheless, it was not possible to produce completely structure-free plates, although they were remarkably clear and the contrast was good. The apparatus also appears to have been fairly large and bulky. It is not possible to ascertain whether this design found any extensive em-

ployment. Considering the resources available at that time, it was probably too complicated.

H. Potter in two reports (1916, 1917) described grid designs for improving picture contrast by reducing, partly the effect of extra-focal radiation, and partly that of secondary radiation, from the object. In his first report, Potter (1916) described a honeycomb-shaped tubular grating which was to be inserted between the tube and the object to reduce the upper group of vagabond rays, the off-focus tube radiation. It consisted of a cross-member system with square openings. Potter demonstrated that diagonal travel could not be used, no more than circular. He thought that deviations from the diagonal motion would be better, but advocated a peculiar motion composed of four alternating directions following a course which suggested the sides of a square. In 1917, Potter discussed the secondary radiation from the object and reduced it with a revolving disc-like diaphragm with lead bars as sector elements. It was especially adapted to fluoroscopy.

In 1920, Potter declared that he had found no way whatever of using a quadrangular network of Bucky's type in order to eliminate the objectionable pattern in the radiographic plate. In a paper of July 1920, he makes this comment: "It is obvious that no circular, linear, or irregular motion can be applied to the grid of square-shaped tubules, such as was described by Bucky, so as to result in equal distribution of shadows over each portion of the silvered plate."

Owing to Potter's great authority, this statement has probably influenced development. Thirty years later, the same views are still held among extensive groups of radiologists and are presented without any further reason. The opinion is sometimes expressed that the points of crossing in the grids will always produce shadows, which no kind of motion whatsoever will prevent. For the sake of correctness it should be mentioned that with the reliable construction of single parallel grids, which was developed at about that time and subsequently, there was hardly any need for cross-grids. First of all, the voltages employed were low; secondly, the low performance of the apparatus would have been reduced still more owing to the simple fact that cross-grids absorb more radiation. In his paper of 1920, Potter outlined the basic principles of the apparatus which bears his name over large parts of the world — a parallel grid which was made slightly concave for the sake of centering and which travelled a distance of a few inches during the exposure. The speed of travel was regulated by an oil drag with a valve in the piston. Potter also presented excellent illustrative specimens.

This construction by Potter appears to have been fundamental, and superior to similar arrangements which were introduced at that period. As early as 1918, J. B. Tauleigne and G. Mazo described a clockwork-

driven single grid with parallel members. It was also centered for a fixed focus-to-plate distance. This movable single grid would eliminate the pattern obtained with BUCKY's device which, in the writers' opinion, was rather disturbing. In a patent of 1922, G. BUCKY described an improved single grid construction. The centering, in spite of the movement, was always perfect, since the grid members were always turned by mechanical means into exact position in relation to the beam.

From this time the cross-grid principle seems to have lost its attraction for a fairly long period, and, in the literature, improvements on the single grid are numerous. Only a few of these will be mentioned in passing. H. LINDSAY (1922), B. W. POWELL (1923), P. C. HODGES (1923) and R. HERDNER (1927, 1928) discussed various electrical implements for synchronizing the motion of the grid with the exposure and for the control of motion. These, and other improvements, made the mechanism more versatile for everyday routine work.

Other principles of movement were also taken up at an early date. As mentioned above, POTTER, in 1917, had demonstrated the possibility of using a rotary grid. As a means of obtaining an improvement in the filtration of secondary radiation — which is not adequately controlled in certain directions by a single parallel grid — Å. ÅKERLUND (1923) outlined the principle of a thin rotating diaphragm of spiral design, which gave most excellent results. The central spot of this diaphragm, however, was visible in the radiograph, which appears to have been a certain disadvantage. ÅKERLUND reported that W. OTTO (1914) and E. CALDWELL (1916) of Berlin and New York, respectively, had patented constructions of similar types. Their devices, however, were not mentioned in the radiographic literature then or later, and apparently production was never started. In 1923, H. S. SAWFORD described a flat rotating spiral diaphragm fairly like that developed by ÅKERLUND, and, in 1924, also presented new modifications of the rotating spiral which was made of smaller and more easily manufactured components. J. ZIEGLER (1924) also used the rotary principle in a disc with wedge-shaped radially arranged lead elements. In 1929, ÅKERLUND described a special model of a spiral diaphragm designed for use with spot-film radiography, *e. g.* for the study of the duodenal cap, the gallbladder, etc. In this construction, the central part of the diaphragm was not utilized.

In general, there seems to have been a great need for simple grids which could be used vertically if needs be, *e. g.* for the examination of patients erect in the radiographic equipment of FORSSELL's design. About 1928, LYSHOLM began to work on grids of such fine dimensions that, when used stationary, their structure hardly interfered with the roentgenogram in the majority of exposures, according to the standards of that time. The slats of these grids were placed with an interspace of

no more than about 0.4 mm and the grids were only a few millimetres in thickness. Such grids, so-called 'fine grids', generally named after LYSHOLM, were increasingly used. They were manufactured by G. SCHÖNANDER of Stockholm, and were made with a precision which soon made them well known all over the world. In the early 1930s, attempts were made to construct the grids wholly of metal, using aluminium to separate the lead strips instead of board or fibre. It was found that BUCKY, as early as 1915—1916, had outlined all-metal grids of this type; owing to production difficulties they were never manufactured, although they are described in the patent literature of those years. When SCHÖNANDER took up the problem, the patents were no longer valid. But the mechanical facilities were greater, and intimate co-operation between LYSHOLM, SCHÖNANDER, and S. LEDIN, grid designer of the Schönander Company, resulted in manufacturing methods for this all-metal grid which gave a very high degree of precision.

From the exclusive use of wide-space systems of moving grids the general trend has thus also progressed towards a common use of stationary fine grids. Moving grids are preferred for the majority of exposures in which fine details are especially desirable, such as skeletal radiographs.

The light fine grids had many advantages. They could be used in numerous cases in which previously no secondary diaphragming had been possible, they facilitated fluoroscopy, and they produced, in spite of the visible pattern, very good films for many purposes. W. EBERHARD (1942) and J. D. CAMP (1947) described grid-fronted cassettes as a useful application of stationary grids. These have served quite well, for instance in connection with 'portable' radiography and in war-time practice.

While this progress was being made, the moving grid system became increasingly easy to handle and well adapted to a variety of purposes. Different applications as described by POTTER (1931) in two reports may be quoted. These refer to devices and apparatus for the improved examination, including stereoscopy, of the paranasal sinuses and mastoids. P. F. COLE (1933) described a means of examining the sinuses which resembled those just mentioned and which made it possible for the roentgenography to be carried out with grids at any angle, the setting of which could be adjusted on a scale. The principle is applied in LYSHOLM's skull table.

Along with this adaptation of the grid and simultaneously with the conquest of new fields, the physical problems concerning it have come increasingly into the foreground.

Among earlier works dealing with secondary radiation from the body irradiated in radiography may be mentioned a paper by J. S. SHEARER (1917) which illustrated the distribution of this radiation by certain

radiographic experiments. He also discussed the Bucky grid. It appears that approximately from this time only such devices as were placed between the patient and the film emulsion were described as secondary diaphragms according to POTTER's or BUCKY's designation. The secondary radiation emanating from the tube will thus in the following not be the principal object of interest.

In 1921, WILSEY presented a very comprehensive study of the effect of secondary radiation in radiography. He paid special attention to primary diaphragming in this paper. In 1922, WILSEY, in two papers, reported investigations of the efficiency of different grids of varying dimensions, and also analysed the importance of the ratio. Higher values gave a more marked retardation of the secondary radiation. He also stressed the importance of the close proximity of the film to the grid, a point which was also emphasized by W. C. ALVAREZ (1923).

In 1924, A. H. COMPTON discussed the fundamentals of scattered radiation and its wavelengths for different directions of propagation. Observations on grid diaphragms were made by H. LEWIN (1927), who pointed out that certain disturbing influences are produced by the grid, partly through its own capacity of spreading secondary radiation. In the border zones between regions of different illumination, a remarkable degradation of sharpness may thus be obtained, the result being a distorsion of the radiographic representation. POTTER (1931) discussed the fundamental principles of grid design and stressed the value of the appropriate ratio and the importance of centering. In another work, POTTER (1931) defined more accurately the importance of the direction of rays in relation to the orientation of the grid slats and defined a shut-out point where the primary radiation is completely stopped. POTTER further discussed, among other things, the production of a visible pattern in the film, *e. g.* through near-pulse grid unit synchronism. In 1934, WILSEY reported the results of a study on scattered radiation in chest roentgenography. He used small lead balls producing shadows, the density of which could be measured and compared with test exposures on the same film. With ordinary techniques, about 50 % of the radiation reaching the film will usually produce fog. With a grid ratio of 8 : 1, better results are obtained at 100 kV than at 40 kV without any grid. The effect was more obvious with larger patients. An important point was made by WILSEY, who stated that the influence of the tube voltage on image contrast is often concealed by the dominance of secondary radiation, an elimination of which would materially increase the influence of the tube voltage on image contrast.

In two reports in 1934, R. H. DE WAARD pointed out the importance of secondary diaphragm efficiency to the contrast in the image. He defined the word 'selectivity' as an expression of the versatility of the

grid. G. Spiegler, in 1935, discussed scattered radiation and its effect on the radiographic image. He pointed out that the effect of a single grid is not the same for details and contours with different orientation in relation to the direction of the strips of the grid, which only stop the scattered rays from certain directions. Spiegler also stressed the importance of the position of the actual detail in the scattering body. Scattered radiation contributes to form the image, but in a diffuse manner. The maximum loss of definition is obtained when a sharp detail is superimposed with a blurred shadow with an edge zone of 2 to 3 mm. With a wider edge zone, or diffuse scattering, as well as with a narrower zone, better definition is obtained, according to Spiegler. Considering the limited effect of the single grid, as shown above, a cross-grid system would be preferable.

Simultaneously with the progress described and with the research made in the field of parallel grids, certain more unorthodox designs, involving unusual principles of movement, were also developed. The background was perhaps that single parallel grids and the arrangements for their motion were regarded as unsatisfactory. An example is R. Imbert's development (1933) of a 'grille cylindrique', a system of tubular elements assembled into a large 'honeycomb' which was given a specific rotary movement when in operation. Imbert reported that certain speeds were liable to produce stroboscopic phenomena. His construction had no doubt some points in common with Bucky's design of 1915. It is also necessary to mention another principle of movement, which seems to have been described first by Bucky, who patented it in 1922. Bucky used a system of chains which supported the metal strips; these could thus move continuously since the chains were endless. After passing over the plate, the grid members returned under the cassette box. Centering was also possible since the strips turned in a special way when passing the plate. The use of two layers of such moving components was also discussed.

A similar principle of movement was described by A. L. Soresi (1931). An endless belt carried the grid elements and passed over two rollers. Judging from the description, the apparatus seems to have been somewhat unwieldy. These constructions by Bucky and Soresi have probably not been much in use.

In 1950, O. Norman demonstrated a very versatile construction of an endless-belt grid. The apparatus was scarcely larger than an ordinary single-grid driving device. By 1953 developments had been made and a kind of cross-grid function was obtained. The belt passed over the film in two directions at different levels. The lead element formed an oblique angle with the longitudinal direction of the belt.

The use of crossed fine grids was also suggested, and this idea was presented, among other things, in a paper by K. Lindblom (1934), in which a comparison was made between different grids as regards their capacity of reducing secondary radiation, tests also being made with thin metal foils. The most favourable results were obtained with cross-grids. A type of moving cross-grid (Lindblom-Schönander) was also mentioned. The paper said nothing about its construction; according to Lindblom an oblique movement had been employed, although it was not very precisely defined mathematically. This construction had been tried as early as 1929. Good results were obtained, but apparently the time was not ripe for practical evaluation. The need of such a grid and the opportunities of profiting from it were not very apparent with the technique of that time.

Some interesting patent applications were made in 1936 by F. Timmermanns; they were made public in 1938 and 1939. He had constructed a cross-grid device, consisting of two single grids supported by eccentrics. These imparted a circular motion to every point of the two grids, and, in addition, balanced each other as counterweights. In order to reduce stroboscopic phenomena, an adjustment of the speed to the current impulses was also discussed. Timmermanns had also made grids with zig-zag strips, with a subsequent decrease of line formation on movement. A kind of rotating grid with similar strips was also discussed.

The literature on moving cross-grids is lean. According to information from technical experts, a French firm, Gaiffe, manufactured a moving cross-grid in about 1930. It was composed of two single parallel grids placed one above the other, with a slight deviation from a right angle. The movement was produced by a separate slit arrangement acting diagonally. This apparatus apparently absorbed too much radiation considering the roentgen equipments then in use, and never found any extensive employment.

In 1938 H. Chantraine patented a system for the elimination of visible structures in films obtained with cross-grids. He used a direction of movement for rectangular or almost rectangular grids which deviated by only a few degrees from the diagonal. There are no detailed data of the grids concerned or the angles involved. The literature contains no precise information on how this design functioned in practice.

After 1940 the efficiency of radiographic apparatus began to increase more definitely, and as higher kilovoltages commenced to be a practical proposition, it is a matter of no surprise that K. C. Clark (1953) in a paper on high-voltage technical problems (up to 120 kV) also described a moving cross-grid. It was manufactured by the General Radiological Ltd., London, after the French prototype described, and had two single grids one above the other with a deviation of 3° from a

right angle between the grid strips. The movement was an oscillating one and followed a diagonal direction, *i. e.* at an angle of 45° from that of one of the sets of strips. Good results were reported, and I have examined films produced with this type of grid which appear to be fairly satisfactory. CLARK had found that a cross-grid has approximately the same efficiency as a single grid with a ratio corresponding to the sum of the ratios of each single component of the cross-grid.

In studying the literary information on moving cross-grids one obtains a general impression of its vague character. Some less well-defined types of oblique movements were described by CHANTRAINE (1938), while other authors preferred a diagonal movement with a grid which differed somewhat from the square pattern. In none of these cases is there any indication whatever of the dimensions of the pattern. It may rightly be expected that these dimensions, especially the relation between the space separating the lead strips, and their size — the interspace factor — will play an important part. In fact, they vary a great deal. A grid of the heavier type with lead strips separated by fibre, may have an interspace factor of perhaps 10. In a finer grid it would be perhaps 7 or 5, and there are in fact grids with an interspace factor of 3. W. WATSON (1936), who presented an extensive review of stroboscopic effects with grids, also counted with a considerable variation of these values, and even took it for granted that the strips may be wider than the interspaces.

The literature reviewed here affords no explanation why a certain degree of elimination of disturbing pattern seems to be possible in using moving cross-grids. There remains a constant feeling of uncertainty, and POTTER's words still remain in one's memory.

At the same time, voices were raised which maintained that the fine grid structure of a stationary grid was of no importance. In 1941, SCHÖNANDER declared that a grid of the fine-grid type "is so fine that it scarcely interferes with the detail of the picture". There were also some who maintained that the thickness of the grid strips, being perhaps no more than 0.05 mm, would cause no interference as the resolution of the screens was of a magnitude above this value. It was also considered that the value of a possible increase in detail definition would outweigh the complexity which is the consequence of a moving system compared with a stationary one.

An up-to-date comparison of different types of grids was made by A. NEMET, W. F. COX and T. H. HILLS (1953), including, among other things, a listing of their efficiency for various voltages at different ratios. Cross-grids were included in the survey and the authors found an approximate correspondence between a single grid of a ratio of 16 : 1 and a cross-grid of a ratio of 6 : 1 for each grid system. These figures, which of course give merely an approximate picture of the relationships, show

that cross-grids are preferable from many points of view. The high-ratio parallel grid is difficult to manufacture and requires a considerable degree of exactness in adjustment because of the centering. It can hardly be moved very much without attaining positions where the primary rays will partly be cut off. Cross-grids, on the other hand, can be moved without this disadvantage, they are not so sensitive with regard to centering and are cheaper to manufacture. Only for roentgenograms requiring an angled beam of rays is the cross-grid less useful.

Surprisingly, E. D. Trout and J. P. Kelley, in a report (1954), make no mention of cross-grids although they have tested single grids with a ratio as extreme as 34 : 1.

The ever increasing demands for secondary screening, which have been a consequence of rising tube voltages, necessitate the use of higher ratios. On the grounds given above, it seems a natural thing to accept cross-grids. All practical tests point in the same direction. On account of their more complete filtration of scattered radiation, the dependence on primary diaphragming is somewhat smaller. With the technical resources of today, cross-grids unquestionably seem to be the answer.

E. Buchheim, in 1952, in his study of high-voltage problems up to 150 kV also made use of cross-grids. Their effect was in every case superior to that of the single ones.

THE PROBLEM OF MOTION IN CROSS-GRIDS

Formulation of the problem

In view of all the opinions quoted above I cannot refrain from penetrating to the bottom of the problem. The questions of vital interests are the following:

1. Is it possible, from a mathematical point of view, to obtain films completely without stripes by means of a cross-grid of arbitrary dimensions?
2. If so, in what manner should the grid be moved?
3. What is the effect of the superimposed network of squares on the eye's perception of fine details?

Some introductory photographic tests

To obtain a preliminary idea about the importance of an oblique movement of cross-square systems as a method of compensation for irregular illumination, I have carried out some photographic experiments. These were made with magnified grid models which permitted a very critical evaluation of the results, and by isolating the test from the influence of radiographic technique, screens, and so on, the real effect could be judged more accurately.

By photographic methods a square system was produced which in its dimensions corresponded to a greatly magnified metal grid of conventional type. This system, which was printed on a glass plate and the geometric design of which satisfied high demands of accuracy, was placed in a projector with an anastigmatic lens, well corrected against distortion, and was projected on a surface over which a slide could be moved at certain predetermined angles relative to the orientation of the system of squares. The size of this system when projected corresponded approximately to a linear magnification of 40 times a metal grid. The slide carried a photographic paper which was illuminated by the projected grid while the latter was moving. The speed was maintained at a level which in relation to the size of the squares reduced the risk of stroboscopic effects, a possible complication since the light source of the apparatus was connected to an a. c. supply. However, the light source, an incandescent lamp, supplied a more regular flow of light than a fluorescent tube. A long series of tests were made to find out if, and when,

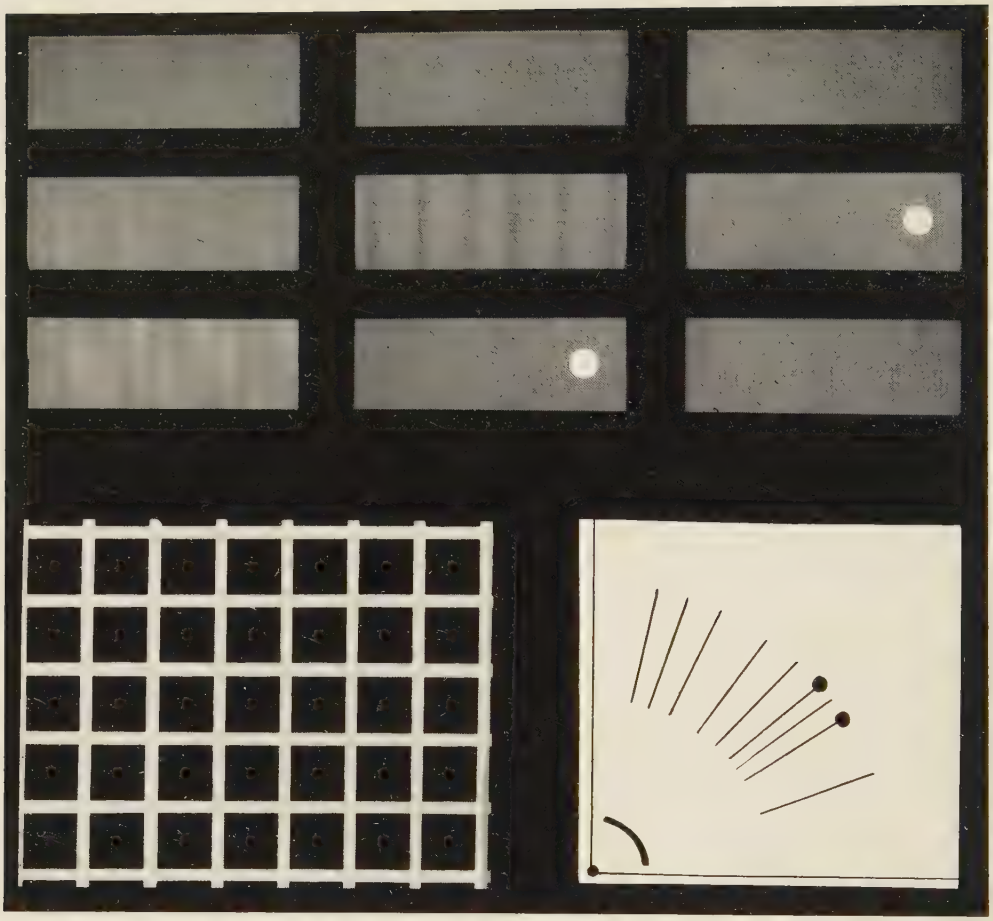


Fig. 34. The effect of varying directions of motion of a grid pattern (bottom left corner). The grey fields above show different degrees of line formation, produced by the movements indicated below. The white and black spots indicate directions where no striping appears.

completely homogeneous illumination could be obtained. A selection of these tests is shown in Fig. 34, which illustrates varying degrees of parallel line formation. Some of these show a strikingly homogeneous illumination. The directions of movement for the tests shown are listed in the lower part of the figure, and favourable directions are marked by black spots; they correspond to the tests showing least structure, which are indicated by white spots. The grid pattern is also shown.

From these tests, which formed the introduction to a more detailed study, it may be concluded that there are good opportunities of re-

ducing the longitudinal lines produced by cross-grids. The fairly common conception that the points of crossing in a cross-grid will always produce lines, independently of the direction of movement, could thus be refuted.

Furthermore, when screens are used and the dimensions of the grid elements amount only to fractions of a millimetre, minor lines will not be visible. With coarser grids and in view of future refinements in the technique it seems, however, to be of the greatest value to make a thorough investigation of the exact optimal angles of motion. It is also necessary to consider the very high degree of resolution obtained by various modern radiographic methods, *e. g.* xerography. It is also true that, however perfectly centered, a grid will be struck by radiation under slightly varying angles during its motion, and that the irradiated surfaces produced by the system of strips of the grid will therefore vary slightly in shape. This contributes to line formation which, however, will be a minimum if the optimal direction of motion has been chosen.

Distribution of illumination — a geometrical analysis

In the following the purely geometric conditions of cross-grid motion will be discussed, and their theoretical background will be studied and clarified.

From the experiments, as well as from some of the comments quoted in the historical review, it appears that it would be possible to suppress very definitely the tendency of visible structure in a radiograph made with a moving cross-grid. It will be shown that there is a theoretical possibility of obtaining an absolute freedom from lines, since it is geometrically possible to achieve homogeneous illumination of the surface situated behind the moving grid. It is assumed that the movement of the grid is of sufficient amplitude relative to the period of time. Purely geometrical relationships must be utilized, and the desired result may be obtained in different ways although always by oblique linear movement. The direction is by no means arbitrary. As will be shown, it is distinctly defined for each type of grid; it varies with the interspace factor, and is primarily connected with the relation between the latter two. Earlier literature, although including patents, reporting that freedom from line formation has been obtained by some kind of oblique movement, gives no information whatsoever about the characteristics of the grid. The interesting laws which reign here — based on simple geometrical principles — have not been discussed previously, which justifies an examination of this problem on the basis of certain experiments, particularly since the problems have come into the foreground lately.

The principles of optimal grid motion are best clarified by certain simple and instructive examples.

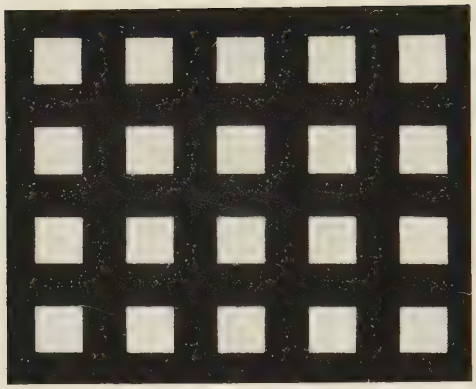


Fig. 35. The grid system used to demonstrate the distribution of illumination in grid motion. Interspace and slat width are equal (interspace factor = 1).

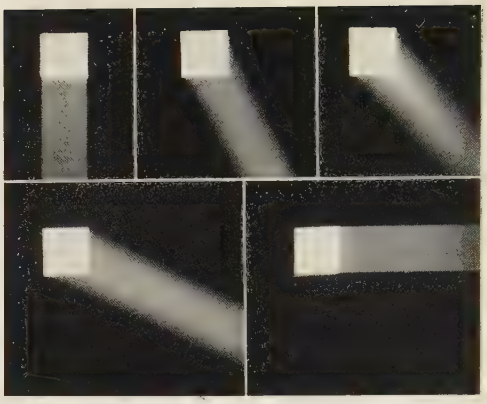


Fig. 36. Lanes of light produced by a single square moving in different directions.

As the first object for demonstration, a very simple grid system, in which interspaces and strips have the same width, has been chosen (Fig. 35). Such a system (interspace factor = 1) scarcely exists in practice, but is well suited for a demonstration of the general geometrical foundations for the achievement of homogeneous structure-free illumination in the picture by the use of special directions of motion. It will be shown that the principle is generally adaptable to all other grids with arbitrary variations in interspace and strip-width.

Fig. 35 and the following figures which demonstrate the distribution of light were produced in a photographical way similar to the principle used for the introductory tests, by means of a projection system and a slide mechanism.

A cross-grid may be regarded as composed of a considerable number of similar grid elements which all transmit uniform bundles of rays. On the sensitized surface these rays produce a number of closely spaced small squares which are all located in a characteristic manner in relation to one another.

If the grid moves, each one of these small illuminated squares will produce an illuminated streak on the film. The appearance of each of these 'lanes' of light depends on the direction of movement of the system, *i. e.* the direction in relation to the orientation of the squares. Fig. 36 shows the appearance of the lanes produced by a single square moving in different directions. It will be seen that there is a considerable variation in the distribution of illumination in the respective lanes. A somewhat larger section of a grid, such as a row of squares, will of course, when in motion, produce a series of similar lanes, as shown in Fig. 37.

Fig. 37. A row of square producing lanes of light. Compare Fig. 36. Lanes located between the original ones (at bottom) may be expected to supplement the illumination up to complete homogeneity.

It is evident that by varying the direction of motion we must arrive at one direction where the series of lanes are situated in such a manner that a compensating interaction with another row of squares is possible. Lanes of light located between the original ones, as indicated by the lower part of the picture, will fill out the interspaces and give supplementary illumination up to complete homogeneity. The distribution of light within the respective lanes and interspaces renders this very possible. Fig. 38 shows how such compensating interaction is achieved by the use of a suitable oblique motion. In a section of the grid consisting of two rows of squares these combine to give homogeneous illumination.

A larger grid may be said to consist of a great number of small elements of this kind, each of which, by local interaction, produces homogeneous illumination. The total effect will be a uniform structure-free illumination of the film as a whole.

Fig. 38. Two rows of squares, forming a section of the grid, combine to give homogeneous illumination when moving in a suitable oblique direction, indicated by the arrow.

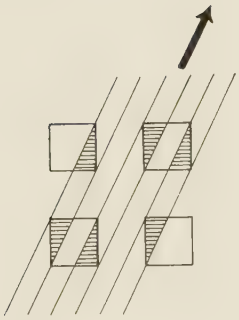


Fig. 39. Interaction of moving squares produces homogeneous illumination. Summation of the shaded corners makes the distribution of light uniform.

The geometrical background of this interaction is easily demonstrated. Fig. 39 shows the general outline of a compensating system of the type now discussed. For a motion producing a homogeneous picture, such as represented by the arrow, the total area of the light-transmitting grid elements passing is constant over the whole of the surface. Summation of the shaded triangles makes the lanes of light pass over into each other without visible borders. The conditions required for homogeneity of the picture may be fulfilled in different ways. Fig. 40 shows one example. The two directions indicated by black arrows may be regarded as reflections of each other; the shaded arrows correspond to the same angles, only with the other grid component as a starting point. As a rule the suitable direction of movement is obtained by connecting two corners of a square with two corners of a square in another row, the respective corners limiting the opposing parallel sides of the respective squares. The angles to be considered are well defined and may be represented by purely mathematical means. The tangent of the angle α in the picture is equal to the relation between the width of the grid strip and the sum of interspace and strip width, and this may be applicable also to other types of grids.

The possibility of compensating interaction with another adjacent row besides the nearest one should also be considered. In that case, the

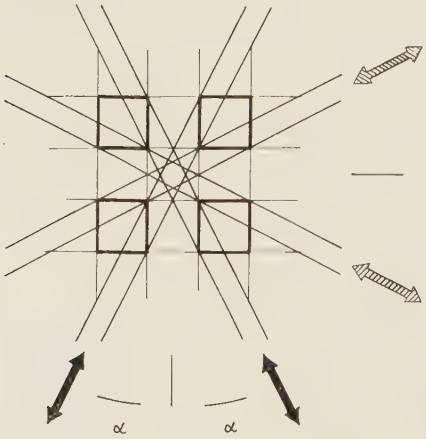


Fig. 40. An example of directions of motion producing uniform illumination; all have the same angular value.

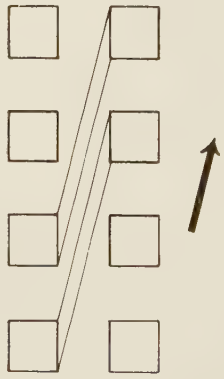


Fig. 41. An illustration of the interaction between different rows of squares not close to each other, for the purpose of homogeneous illumination.

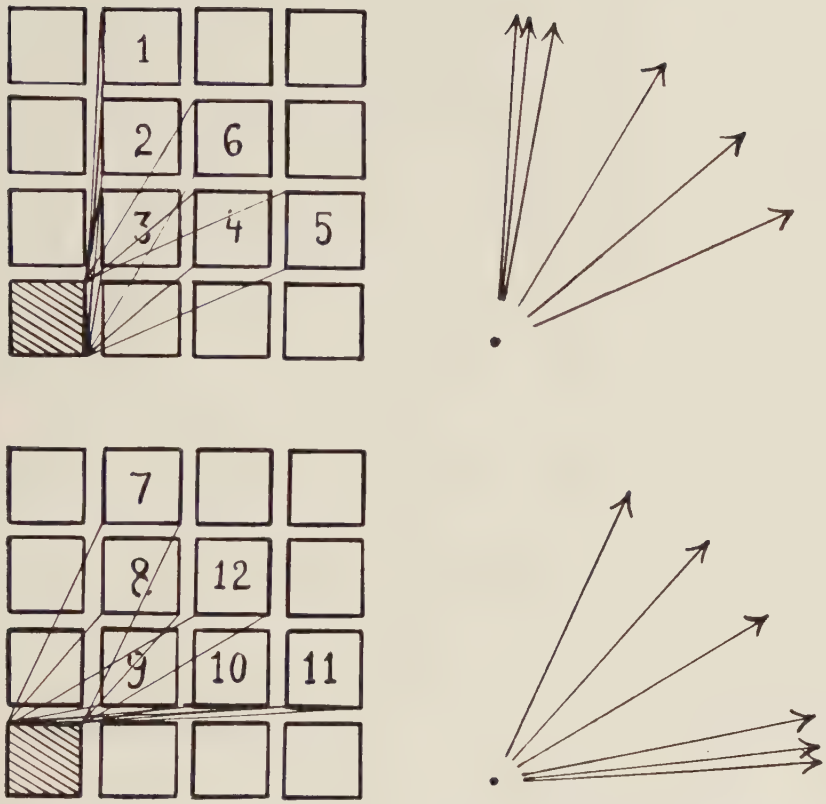


Fig. 42. Possibilities of motion with a grid of ordinary dimensions (interspace factor = 5). The shaded square and the numbered squares will interact. The directions are indicated on the right.

interacting systems will be interwoven with each other in the grid: thus, if the rows of a system are numbered, rows 1 and 3, or 2 and 4, will be interacting. (See Fig. 41.) Longer intervals between the rows may also be considered: in this case new angles of movement will be implied.

Applications to conventional grids

The basic principles outlined above are characteristic of all types of rectangular cross-grids, whatever the relation between interspace and strip width. In the grids commonly used this ratio will be something like 5 to 1, *i. e.* the interspace factor is 5. Fig. 42 shows the geometrical relations of movement with a grid of that kind. The shaded square and the squares with numbers interact. There are no less than twelve possibilities available — the directions are brought together on the right side of the

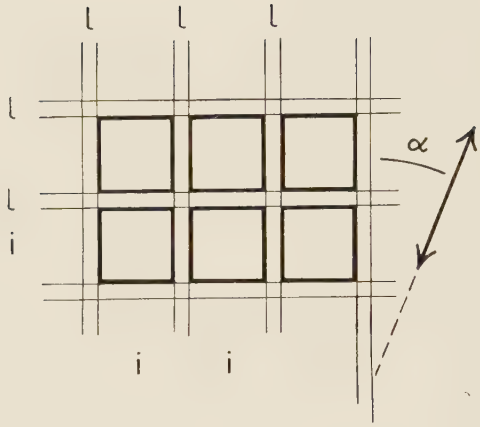


Fig. 43. Illustration of the symbols used in the tabulation below.
(l = lead thickness; i = interspace.)

Tabulation of trigonometrical values of different angles of motion for homogeneous illumination. The symbols are explained in figure 43

$$\operatorname{tg} \alpha_1 = \frac{l}{3l + 3i} \qquad \operatorname{tg} \alpha_7 = \frac{l + i}{3l + 2i} \; (= \cot \alpha_5)$$

$$\operatorname{tg} \alpha_2 = \frac{l}{2l + 2i} \qquad \operatorname{tg} \alpha_8 = \frac{l + i}{2l + i} \; (= \cot \alpha_4)$$

$$\operatorname{tg} \alpha_3 = \frac{l}{l + i} \qquad \operatorname{tg} \alpha_9 = \frac{l + i}{l} \; (= \cot \alpha_3)$$

$$\operatorname{tg} \alpha_4 = \frac{2l + i}{l + i} \qquad \operatorname{tg} \alpha_{10} = \frac{2l + 2i}{l} \; (= \cot \alpha_2)$$

$$\operatorname{tg} \alpha_5 = \frac{3l + 2i}{l + i} \qquad \operatorname{tg} \alpha_{11} = \frac{3l + 3i}{l} \; (= \cot \alpha_1)$$

$$\operatorname{tg} \alpha_6 = \frac{2l + i}{2l + 2i} \qquad \operatorname{tg} \alpha_{12} = \frac{2l + 2i}{2l + i} \; (= \cot \alpha_6)$$

figure — and more may be thought of. Several of them, however, correspond, *i. e.* the same angular value is obtained when measuring from the other grid component. This fact is also clearly shown by the tabulation of trigonometric values presented above. The explanation of the symbols is given in Fig. 43 and simple trigonometric laws are applied.

Of the angles theoretically possible some have to be excluded from practical use. There must be an interaction with a relatively close row, otherwise too great a speed and distance of movement will be required of the grid. A compensating action for homogeneous illumination consists in the passage of two units over the film. These must not be too distant

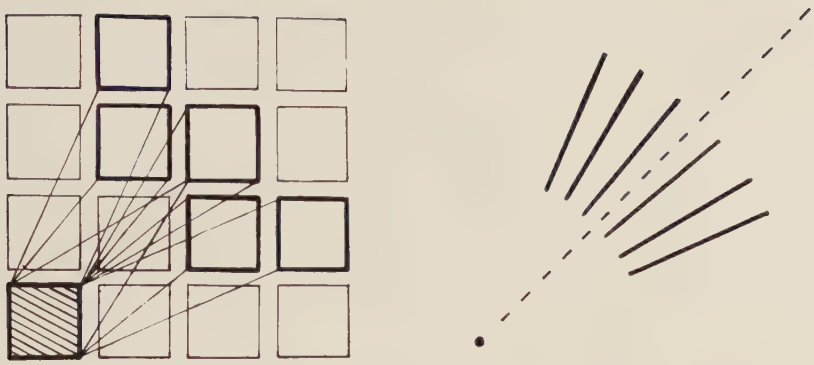


Fig. 44. A selection of six suitable angles of motion and their geo metrical background

from each other. Many such passages will be possible during the exposure, but one of them will perhaps be incomplete. This irregularity in exposure will not be noticeable if it constitutes only a very small part of the total exposure. A similar thing will occur in ordinary single grids. At the beginning of the exposure, some parts of the picture will be shaded by the grid strips and will receive their first illumination later than others. This may be compensated for at the end of the exposure, but often this is not the case. A certain minimum of number of grid units must pass if the summation of exposure impulses is to produce no visible inhomogeneity in the film. The problem was also touched upon by Lotzin (1917) who maintained that at least twelve to fifteen passages are necessary. According to Ledin (1952) the number of illumination changes required is of the order of some 30 for ordinary secondary diaphragms.

Among unsuitable angles of direction may further be mentioned those which approach any of the grid directions. The oblique movement of the grid may be broken up into two component movements, one perpendicular to each grid system. Of course, none of these should be too slow or phenomena of the type just described will appear. The ideal seems to be a direction which gives a sufficiently great component movement for both grid systems. This necessitates a somewhat greater total movement than for a single grid. An additional complication is produced by stroboscopic effects caused by interference by the alternating current impulses which produce an intermittent flow of radiation in the tubes. These effects are more complicated in cross-grids, and will be discussed separately later on.

Fig. 44 shows a selection of six practicable angles of movement and their geometrical background. The angles of movement naturally group themselves uniformly around a diagonal plane of symmetry. Of these six, the middle four will be optimal. (α_1, α_6, α_8 and α_{12}.) They correspond

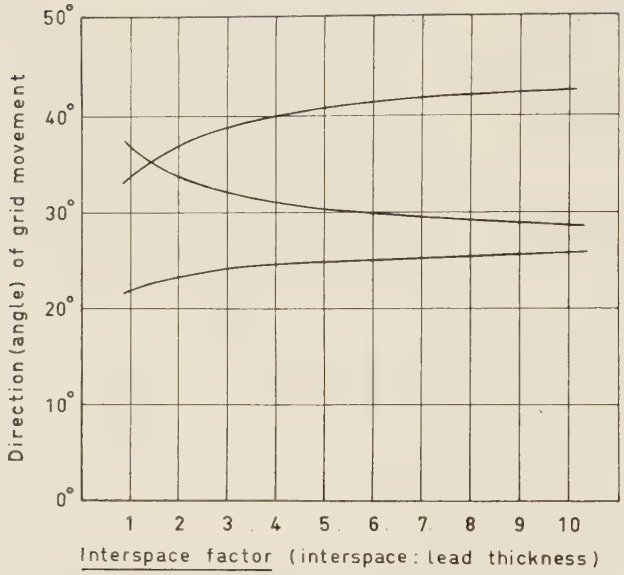


Fig. 45. Angles of motion for obtaining homogeneous illumination for variations in interspace factor between 1 and 10. Refers to rectangular grids with arbitrary dimensions.

to each other two and two as complementary angles, and their tangents and co-tangents agree, as seen from the tabulation below:

Optimal angles of motion for crossed grids. (α_1, α_6, α_8 *and* α_{12}.)
Symbols explained in Fig. 43

$$\operatorname{tg} \alpha_4 = \frac{2\,\mathrm{l} + \mathrm{i}}{\mathrm{l} + \mathrm{i}} = \cot \alpha_8$$

$$\operatorname{tg} \alpha_6 = \frac{2\,\mathrm{l} + \mathrm{i}}{2\,\mathrm{l} + 2\,\mathrm{i}} = \cot \alpha_{12}$$

The great multitude of angles has thus merged into but a few. By using the interspace factor the calculation of the angles will be simplified. The letter symbol l is then changed to the number 1, and the interspace factor is used instead of the symbol i.

Suitable motion of arbitrary grids

Independently of the dimensions of the grid elements, the interspace factor is decisive for the angles of motion. The effective directions of movement for homogeneous illumination for grids of various types are found in Fig. 45. The graph covers variations in the interspace factor lying between 1 and 10 and is applicable for all grids with arbitrary dimen-

sions, if only the two crossed systems are alike. Only rectangular grids are included, and only the three most important directions of movement. Furthermore, only one 45° segment has been observed. The angular values were calculated from the formulae given above. As previously indicated, the same angles reappear as complementary angles, since there is a mirror-reflection grouping of directions around the diagonal, owing to the symmetry of the grid. The angles may thus be counted from either of the grid bars. I refer to Fig. 40. The observed intersection of the upper curves represents a special case when the formulae of both curves indicate the same angular value.

Application to unorthodox grid systems

If angles other than the right angle are used between the strips of the grid system, the relations will change in a characteristic manner. The system of co-ordinates which constitutes the plan for the directions of movement of a certain grid will change, as the grid angle is changed, into an oblique system which will still show full proportionality between the different angles. It may be said that the system has been compressed.

Fig. 46 affords an illustration. *a* (top left) is a system of the type described above with right angles, the directions of motion being shown on the right (*b*). *c* represents a system deviating from a right angle, with a corresponding number of directions of motion shown to the right (*d*). Since the grid is no longer uniformly symmetrical, another series of possibilities, *c* in the figure, is obtained in the direction corresponding to the other diagonal plane. It will be seen that the opportunities of movement in this case are numerous. It is perhaps not surprising that Chantraine and Clark have utilized deviations from a right angle in their constructions. With a 45° angle, as used by Clark, it is quite possible to approach one of the suitable angles with grids of conventional sizes. The interrelation between satisfactory directions of motion and grid data, however, was not discussed at all by these authors.

By a suitable deviation from a right angle in the grid, it will thus be possible, in practice, to obtain useful directions, not only with a 45° angle, but also perpendicularly to either direction of the grid. The latter alternative offers the opportunity of supplementing an existing single grid system in an ordinary moving mechanism with another superimposed system placed at an oblique angle, as calculated above. A system with rhombical openings will then be obtained. The geometrical background of homogeneous illumination in this case is demonstrated in Fig. 47.

A disadvantage of such a system is that the relative motion of the

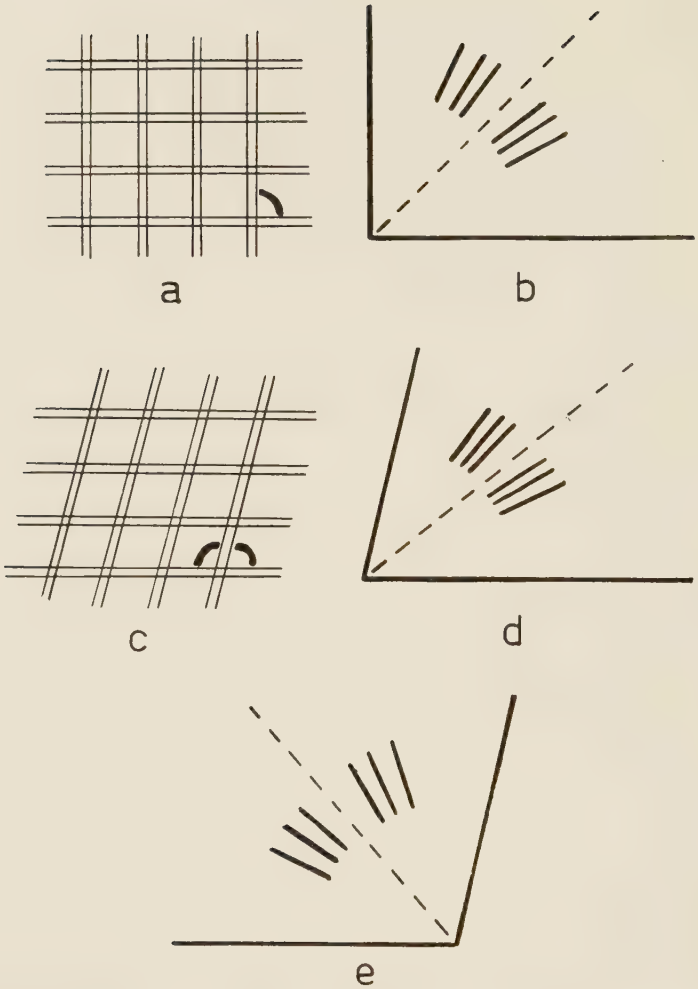


Fig. 46. The effect of deviation from the right angle in a system of crossed grids. *a* shows a system which in *c* is deformed. The original directions of movement represented by *b* will change to those in *d*, but a new series of angular values shown in *e* will also appear.

superimposed grid system will be fairly slight and there is a possibility of irregular illumination. As mentioned elsewhere, a certain minimum of grid element passages is required for uniform illumination.

As soon as the true square shape is abandoned, a certain decrease in efficiency should be noticeable, although not very marked. As shown previously, the efficiency of a parallel grid, of the same height and dimensions as a cross-grid, will be somewhat inferior to that of the latter.

Different values of lead thickness and interspace in two systems form-

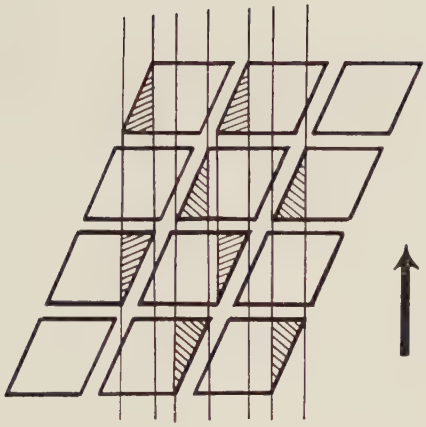


Fig. 47. The geometrical background of a system with rhombical openings giving homogeneous illumination with a movement perpendicular to one of the grid element directions. Summation of the shaded triangles makes the distribution of light uniform. Compare Fig. 39.

ing a cross-grid — conditions sometimes occurring — will not render homogeneous illumination impossible. Perfect results have been obtained in tests. The geometric calculations, however, will be somewhat more complicated than with ordinary cross-grids.

Some practical problems

Cross-grids to be used in a moving system require a higher degree of precision in manufacture than ordinary grids. A small irregularity in a grid element may be without consequence in an ordinary single grid, where the distribution of illumination is not materially influenced, but in the cross-grid it will disturb the regularity of the square system, *inter alia*, the shape and size of the squares, and thus upset the uniform freedom from lines in some regions of the film.

Modern single grid constructions have high ratios, perhaps 12 to 1 or 16 to 1, which means that the height of the strips is relatively great in relation to the interspace. Any movement of the grid must involve the abandonment of precise centering. It is possible to arrange the motion so that the grid, at the beginning and end of its travel, is located off the centre position which it passes at the middle of the movement. This fact complicates the use of all grids. Because of the high efficiency of cross-grids, however, it is possible to manage with so low a ratio in each component of the grid that the problem is of no predominant importance. Through variation in incidence of the radiation for different positions,

however, a slight variation in the size of the illuminated squares is produced which may involve a risk of line formation. In more ordinary grids, with a ratio for each member which may amount to 6 to 1, I have not found any noteworthy influence from this factor.

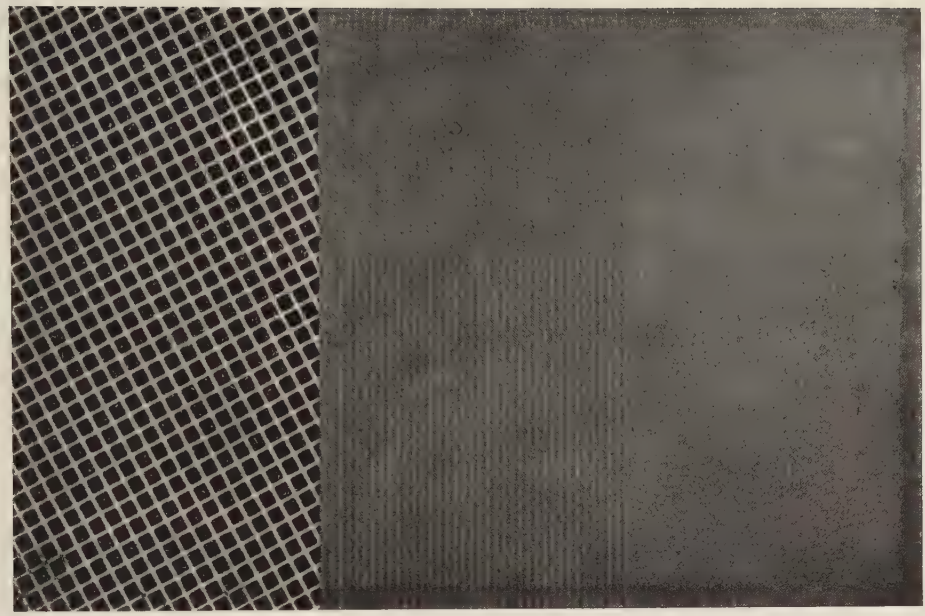
If a very high ratio is used, a tilting motion of the grid might of course be introduced, so that the latter would retain its centered position in spite of the sideways motion. The different positions would always correspond to tangential planes of a sphere with its centre at the focus. The magnitude of transversal motion at the edges of the grid would not amount to more than a few centimetres, as far as normal grid sizes are concerned. In this connection it should be mentioned that certain factors will counteract latent line formation, among these being screen unsharpness. As will be shown below, this tolerance is very narrow.

Effect of deviation from the correct angle of motion

It may be of interest to study the importance of a deviation from the optimal angle of motion. The author has made tests with a grid in which the grid slats had a thickness of 0.08 mm and the interspace was approximately 0.62 mm (interspace factor = 7.75). A calculated angle of motion was a little over 29°. Compare the graph shown in Fig. 45 on page 52. This direction of movement was adjusted and gave perfect results. Small deviations were made and the radiographic results were studied. Ordinary screens were used. It proved that a change as small as 1.5° — the value of the tangent of the angle was 0.02 — produced a manifest change in the appearance of the picture, with a disturbing striped pattern. The test pictures were made without any object, whence there are no superimposed structures visible to reduce the pattern perceptible to the eye. In Fig. 48, *a* shows an enlarged view of the stationary grid, *c* the effect of correct motion, and *b* a stripe pattern generated by the described deviation from the correct angle.

Technical aspects of movement

There are several possibilities of ensuring that the movement of the grid pattern coincides with the angles indicated above. The simplest manner of utilizing a rectangular cross-grid along the lines indicated above is to use a type in which the lead slats have been fitted by the manufacturer in such a manner that the grid pattern forms correct angles with the sides of the grid plate. This plate will then move in parallel with any one of its sides (compare Fig. 48 *a*). A conventional Potter-Bucky mechanism, with for instance a spring drive and oil damper, may



a *b* *c*

Fig. 48. Effect of deviation from an optimal angle of motion of a cross grid. The grid shown stationary in *a* gives, with a correct direction of motion, a radiograph free from striping (*c*). A deviation of only 1.5° from this direction gives a marked striping as shown in *b*.

then be used to advantage. Very small alterations in the apparatus will be necessary apart from an exchange of the grid in its frame; such an apparatus has been used by the author for the angiographic examinations described later.

At present, however, it is difficult to obtain sufficiently large grids. The plant available cannot as yet produce more than a certain maximum width, unless two or more grids are joined. Since oblique angles are employed, the maximum width will be included as an oblique diagonal in the cross-grid. Under the most favourable conditions, the jointless area of an ordinary cross-grid may amount to approximately 35 × 35 cm which, after subtraction of the movement, secures an area of at least 30 × 30 cm. On my recommendation, Messrs. Schönander have attempted to make precision joints, lengthwise as well as across the grid, to such a degree of accuracy as not to be visible with the grid stationary. Joints in grids are not uncommon and often occur in those of foreign manufacture. They are mostly parallel joints, not very neat and quite visible. The type of joint which has been developed here is hardly discernible with the grid in the stationary position, and completely disappears when the grid is in motion.

The problem connected with these grids is not only the joining technique, but the centering of the different sections, which must be uniform for the two sections combined and accurate all over the surface of the grid.

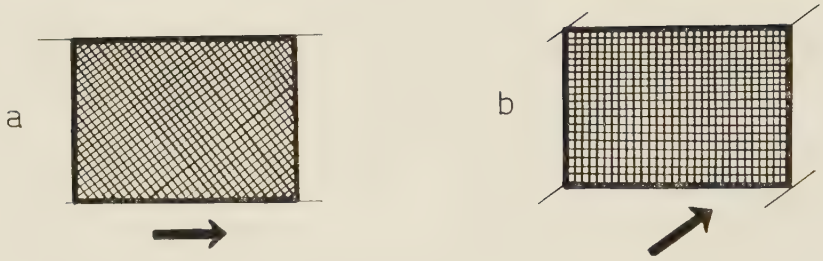


Fig. 49. Two ways of obtaining the oblique movement of the grid pattern. In *a* the grid elements have been arranged obliquely in the grid plate, which moves in a conventional way. In *b*, the grid plate with grid elements arranged in the ordinary manner moves obliquely.

A cross-grid with correct oblique angles of adjustment of the grid slats within the grid plate seems to be a good answer for practical work. When necessary the grid may be exchanged without alteration, and may perhaps be used in other apparatus. If it is desired to tilt the tube in order to obtain an inclined beam, a single parallel grid may be introduced provisionally. Another advantage of this system is that a conventional drive mechanism may be used.

If only smaller inclinations are needed, a large grid with the centering which I have calculated may be used without special precautions, if merely a small picture surface is to be covered. The image is then projected within that section of the grid which has a centering corresponding to the direction of the rays, *e. g.* in the upper part of the grid for rays coming at an oblique angle from below. The principle is demonstrated in Fig. 50. Correct centering up to 10° is then possible for sizes up to 20 × 20 cm. The adjustment of the tube is simple. The direction may be assessed directly if the tube is rotated only around its point of suspension, approximately equal with the position of the focus.

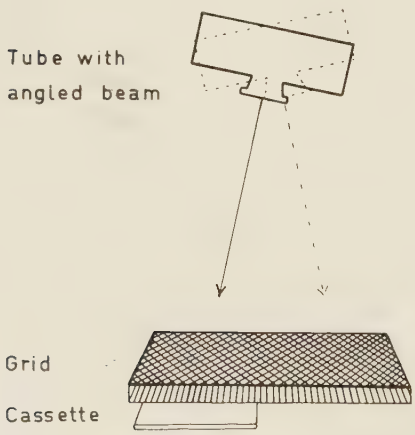


Fig. 50. For smaller sizes of film angled directions of rays may be used with a sufficiently large centered cross-grid.

Another possibility of producing a suitable motion of the grid pattern is to use a cross-grid which has its slats parallel with the respective sides of the grid unit, as is usual with ordinary cross-grids. The grid may then be moved obliquely along a diagonal forming a suitable angle with the direction of the slats (see Fig. 49 *b*). Mechanical arrangements for this purpose may consist of grooves, guide bars or some other adequates mechanism. The use of such a mechanism requires an intimate agreement between grid data and type of movement.

Fig. 51. Two separate single grids, moving individually in perpendicular directions (*a*), may produce an effect similar to that of an obliquely moving cross-grid. The movement of the resulting grid pattern (R) is influenced by the travel of the respective components (A and B) per unit of time (*b*). α is the argle of motion.

In place of a cross-grid composed of two firmly connected systems of slats, one may use *e. g.* two single grids each of which are moved individually so that the same action is produced as with the composite grid. The basic principle is to give the resulting grid pattern a planned motion as described above, and to create the same effect as with the composite grid. With two grids, several different forms of construction may be contemplated. If each of the single grids has its slats parallel and rectangular to the sides of the grid, respectively — and is thus of the standard type — the desired effect will be produced by moving each of the grid elements at right angles to the slats so that the two directions of motion are at right angles to each other. Their speeds should be so accommodated to each other that the resulting action corresponds to an oblique travel of the grid pattern at a suitable angle (Fig. 51, *a* and *b*).

Let us assume that the travel of the respective grid components per unit of time is A and B, respectively. The resulting travel is represented by R. The relation between A and B is given by:

$$\operatorname{tg} \alpha = \frac{A}{B};$$

α being the angle of movement for the resulting grid pattern. By varying the speed relation it is thus possible to simulate any angle of motion.

For practical reasons, a system of motions involving these directions will scarcely arise. It is only of theoretical interest. But the use of two separately moving grid elements affords very extensive facilities for variation. By changing the orientation of the pattern within each grid component, new directions of travel may be obtained, as well as desired relations of speed. In this way numerous possibilities present themselves.

If the grid slats are placed obliquely in a suitable manner in the two single components, the desired effect will be produced, even though the

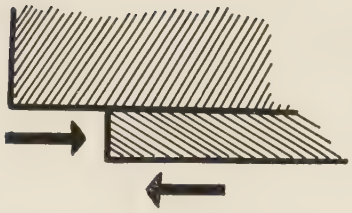


Fig. 52. A reciprocal motion of two oblique single systems may produce a desired motion of the grid pattern.

individual grids be brought into reciprocal motion against each other as in Fig. 52. This permits static and dynamic balancing, which is no doubt of the greatest practical importance, especially when heavy grids are used in non-horizontal planes and at high speeds. It is easy to make these factors clear. Any straight motion of a single parallel grid system may be translated into another, oblique, motion of a system which is correspondingly oblique. There will of course be a loss of distance travelled, and the lost distance corresponds to a parallel travel of the grid, but in return the desired direction will be obtained.

A desired combined motion of the grid elements which gives the squares a definite direction may thus be produced by separate movements of the individual grids, and these movements may be varied

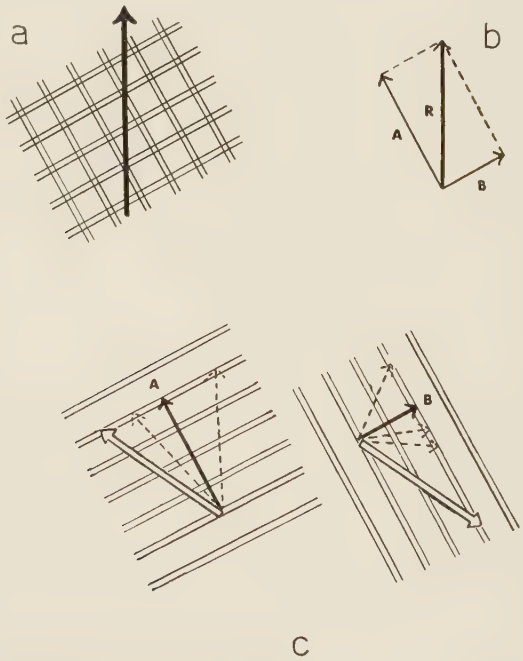


Fig. 53. An explanation of the oblique motion of a grid pattern (*a*) as produced by reciprocal movements of two single systems. The desired motion R may be produced by the movements A and B of each of the systems. (*b*) The white arrows correspond to grid travels giving these movements although they are reciprocal and of the same size (*c*).

within wide limits as regards direction and size. These circumstances are exposed in detail in Fig. 53. If we depart from a pre-determinated resultant motion (heavy arrow R), the effective component movements will first be defined. These represent the two grid element movements A and B (see *b* in the figure). How these are arrived at is of no importance. The arrows represent the effective travel, that is to say, the position of the grid elements at the beginning and end of a defined period of motion. These, however, do not correspond to the real movements, since a greater or smaller amount of parallel displacement may be included in the movement (see *c*). The same result is obtained from essentially different grid element movements, that is to say, the absolute travel of the elements may remain unchanged, while the real travel may assume directions and magnitudes which show great variation. The size of the motion, however, will always at least equal the absolute travel. The dashed arrows represent equivalent movements of the grid which also contain parallel displacements. The white arrows are selected. They are equally large and opposed — the fundamental conditions for freedom from striping are then present together with the dynamic balance.

The purely geometrical conditions connected with equal opposed motions will be analysed briefly to obtain a general idea of the size of the motion. In Fig. 54, as previously, R represents the total travel of the grid pattern, while A and B represent the absolute movements of the respective single grid systems. N_1 and N_2 represent the real travel of the grid plates. Of the complete triangles, which are congruent or reversely congruent, it is easy to calculate that R will be equal to both N_1 and N_2. The opposing component movements are thus of equal size with the movement of an ordinary composite cross-grid, if such a grid be used. This seems to apply generally. The original angle of motion, which complies with the composite cross-grid, is here reproduced in the form of the two moving grid components.

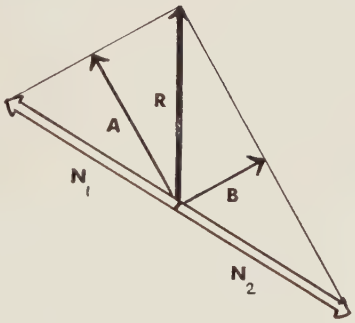


Fig. 54. The geometrical conditions with equal reciprocal motions. R, A and B are known from Fig. 53. N_1 and N_2 are the opposed movements. Four congruent and inversely congruent triangles are formed, which simplifies the calculation of travels and angles.

It is impossible to fulfil the demands on a structure-free radiograph if the two grid components moving against each other are parts of an endless belt. The same oblique orientation of the grid elements will then appear in each layer, but one of them is turned over. The resulting effect will be more or less rhombical openings or squares, which because of the symmetry of angles move in a diagonal direction, at right angles to the longitudinal direction of the belt. There are conditions favouring a parallel striping with arbitrary orientation of the grid elements.

The reason why I have dwelt at length on these questions is that when rapid movement of the grid is used, it is necessary to employ a

counterweight to balance the mass of the grid, which may be considerable. A simple and attractive solution to the problem is to utilize the grid elements as reciprocal counterweights in this way.

In the above, I have discussed the purely geometrical fundamentals for complete uniform illumination behind a cross-grid without any tendency towards parallel striping. The assumption is of course that the grid is permitted to travel far enough, and with uniform speed, across the photographic film, and that effects of intermittent illumination are neglected. The lack of uniformity in illumination which may sometimes occur and which is due to the intermittent flow of radiation in the tube will be especially commented upon in another chapter.

Loss of definition with a superimposed grid pattern

The presence of a superimposed grid pattern in the radiograph constitutes a considerable handicap to the eye. In what follows we shall restrict ourselves to cross-grids, which are of principal interest in this connection. Some explanations of the disturbing effect will be given.

The grid slats in themselves shade part of the picture, and the cutting up of the picture into numerous small elements presents great difficulties to the eye. The continuity of the rendering is interrupted and the eye cannot easily apprehend the infinitesimal detail in each section between the lead slats. The eye tends to create for itself a kind of average impression of the density of the small surface, devoid of all detail. This, in combination with the absence of connecting parts in the picture, contributes to make the evaluation of detail still more meagre, since the eye has an unconscious tendency of filling out the missing pattern with the level of blackening of adjacent parts.

An effect produced by the grid may be that a small point-shaped detail exactly filling one square appears, to the eye, to be enlarged through summation with neighbouring grid bars. On the other hand, detail which is more or less hidden behind a grid bar may completely disappear, or, to a considerable extent, be suppressed. A detail which only fills a small portion of a square in the grid is often underestimated in importance by the eye, while the size of another which fills the main part of the square may be overestimated. A contour of the object which runs obliquely to the grid elements will therefore not infrequently have a saw-tooth appearance. The reason is that the squares which are filled in by the main part of the object will dominate others which only include a small part of the latter. Fig. 55 *a* shows an enlarged example of this distorsion of the contour. The same detail is seen to the right in Fig. 55 *b*, photographed exactly in the same manner, but with a moving grid.

a *b*

Fig. 55. A peculiar phenomenon in the depiction of details with a superimposed pattern of a stationary cross-grid is shown in *a*. Certain contours will have saw-tooth appearance. *b* shows the same object with the grid moving. 3 ×.

It is a well-known physiological phenomenon, discussed by M. Luckiesh (1945), among others, that a background of a mesh-like pattern confuses the eye and makes the rendering of detail more difficult even if it is not concealed by the pattern. This fact may partly be explained by a time factor. Objects against plain background are seen almost instantly. On a patterned background it takes time to perceive them. This refers to unbroken details; a radiograph, on the other hand, contains details divided into small elements which must complicate the matter.

H. Franke in some investigations (1941) touched upon the effect of superimposing details and showed the material reduction of visibility with the help of, for instance, yellow peas, of which he used layers of different thickness. The phenomenon seems to be of importance for relatively large structures as well as for those of the size of the grid elements.

From what has been said, it will be apparent that details in the shape of points and lines are unfavourably affected by the grid pattern, and that there is a great risk of incorrect and distorted rendering of these details. It might be expected that elimination of the grid pattern would be of importance, especially in angiography.

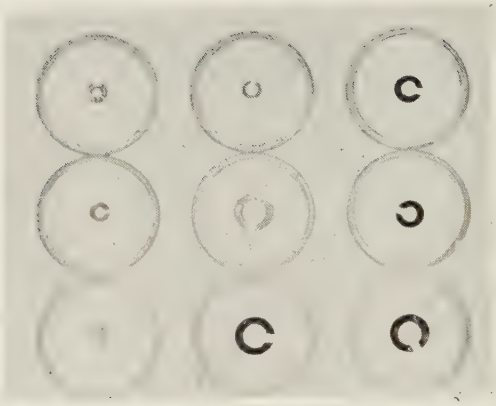


Fig. 56. A detail of the phantom designed by SCHOBER, which was used to study the influence of grid pattern upon the rendering of details. Note the LANDOLT's rings of various size.

In order to arrive at an objective idea of the reduction of visibility through a grid pattern, the author has carried out certain tests with a phantom. The arrangement used for the purpose was the phantom described by H. SCHOBER in 1951, constructed for studies of the degree of definition with various techniques. This phantom contains a number of small rings of aluminium or plexiglass (perspex) with small indentations (LANDOLT's rings). The varying size and thickness of the rings makes them and their details more or less visible in the radiograph. This phantom seems well suited for a general evaluation of the reductive character of the grid pattern. Fig. 56 shows a detail view of the phantom.

A large number of tests were made with varying voltages and exposures, with and without grid motion. The results were assessed by ten unprejudiced observers.

The phantom tests with the SCHOBER arrangement were performed in the following manner. Parallel with the production of the radiographs of the phantom the positions of the rings were registered photographically, as a control. The simplest method, it was found, was to make a paper print of the shadow of the phantom plate as produced by a small source of light, for instance a small bulb. An ordinary cheap document paper was very well suited for this purpose. The same photographic procedure was repeated after each new setting of the rings. An exact control of the readings of the radiographic recordings could be obtained in this way.

The films were studied in a viewing box with fluorescent tubes in the same manner as all other radiographs in the department. The test persons were mainly people very familiar with the study of radiographs. The influence of memory in studying the two identical recordings which might disturb the proper interpretation of the second film in every set, could be eliminated by turning over the latter film and studying it from the other side. The numbers of rings fully visible in the corresponding films were determined. A higher and a lower number was obtained for each set; because of different radiographic technique the level of the numbers varied. Mean values of the number of visible rings were worked out for each film.

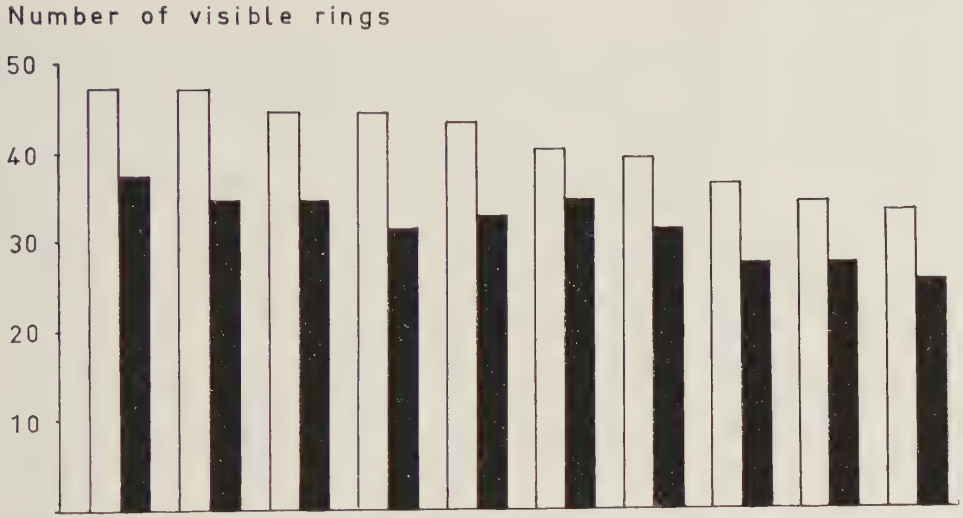


Fig. 57. Experimental results with the phantom of SCHOBER's design. White and black columns represent the number of visible rings with moving and stationary grid, respectively.

The results are reported in Fig. 57, in which each white column represents a moving grid and each black column a stationary grid, their heights representing the number of rings visible. There is a striking gain in detail visibility; approximately 20 per cent more rings are visible when the grid structure is eliminated.

Quite briefly it may be mentioned that there is another disadvantage of a more special nature connected with the grid pattern. In making letterpress blocks — a common procedure for pictures of scientific interest — a half-tone screen is used in the reproduction. It is a kind of grid, its purpose being to divide the picture into small elements which form the dots of the printing block. It happens that the grid pattern of the original interferes with the screen pattern of the block, producing a phenomenon called *moiré* and consisting of peculiar line and square combinations of a disturbing nature. This phenomenon is well-known in the reproduction of originals containing a screen pattern (F. H. SMITH 1948). Although such *moiré* phenomena can mostly be suppressed by slightly rotating the reproduction screen (J. KROON 1935), the question is nevertheless of some importance. Freedom from grid pattern in the radiographic original will thus facilitate the reproduction.

Moving cross-grids in practical use

An example of a radiograph made with a cross-grid moving according to the principles presented is found in Fig. 58, which shows details of radiography of a lateral skull with the region of the sella turcica as center. (Large film.) A small part of the film corresponding to the dorsum sellae is photographically enlarged and presented below (left), compared with the appearance of the same region with the grid stationary (right). Both films were identically exposed in other respects. The difference in richness of detail is striking.

Different experimental models of cross-grid drive mechanisms have been used. One of them, consisting of a fine metal crossed grid built into a Potter-Bucky mechanism of the type used in skull tables, proved most versatile. It could be connected by means of plugs to the electrical systems of the control tables of different radiographic tubes. Synchronism between exposure and grid movement could thus be secured. Because of its small dimensions, it could easily be combined with film changing arrangements for serial angiography. A manual setting of the spring mechanism between each exposure was necessary with this experimental apparatus, but at the low frequencies of exposure often sufficient for angiography this operation was easily performed. The complete grid mechanism, which was no more than about 15 mm thick, was placed directly upon the cassette changer. The area covered by this cross-grid was 30 by 30 cm, which was satisfactory for most of the angiographic examinations.

A number of examinations have been performed with the arrangement described. The greater part of them have been pelvic arteriographies. In these examinations, which are of an increasing importance, the improved definition of detail is a considerable advantage, an opinion expressed by I. Fernström, who has made comprehensive studies of the vessels of that region under different physiological and pathological conditions (1954).

Figs. 59 and 60 show details of two films obtained by pelvic arteriography. There is an interval of about 2 seconds between the two exposures. The exposure time was 0.20 sec. and 110 kV with 150 mA was employed. Ordinary screens were used in cassettes. The examination was carried out for a suspected myoma. The radiograph shows normal appearances. Note the richness of fine details.

The moving cross-grid has also been used for aortography of the kidneys. An example is presented in Figs. 61 and 62, which show details of two films from an examination carried out for a suspected kidney

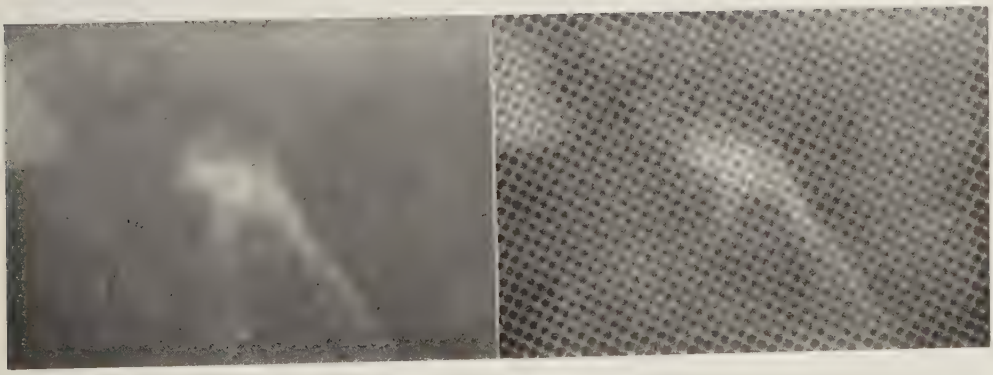


Fig. 58. The sella turcica region of a skull radiograph made with a moving cross-grid is shown in the large picture. A magnified detail of it showing the dorsum sellae is reproduced below (left). Notice the improved rendering of details in comparison with the small picture made with the grid stationary, but with the same exposure data (right).

Fig. 59.

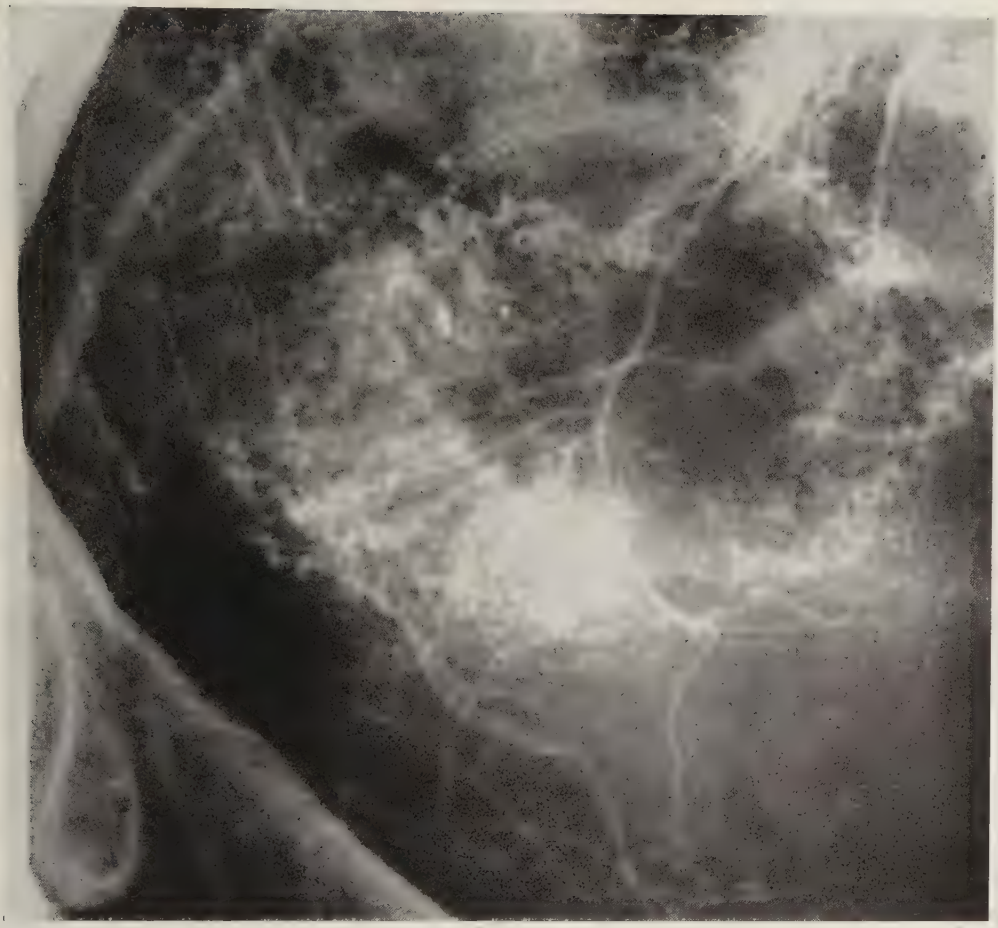


Fig. 59 (opposite) and Fig. 60 (above) show details from a pelvic arteriography. Linear magnification 1.7 ×, interval between exposures 2 seconds. Moving cross-grid with ratio 5.5 : 1 on each system, interspace factor about 7 (Schönander metal grids). Angle of motion 29°. Exposure 0.20 seconds, 110 kV, 150 mA. Catheter inserted in femoral artery; the examination was made because of a suspected myoma.
The films show normal appearances.

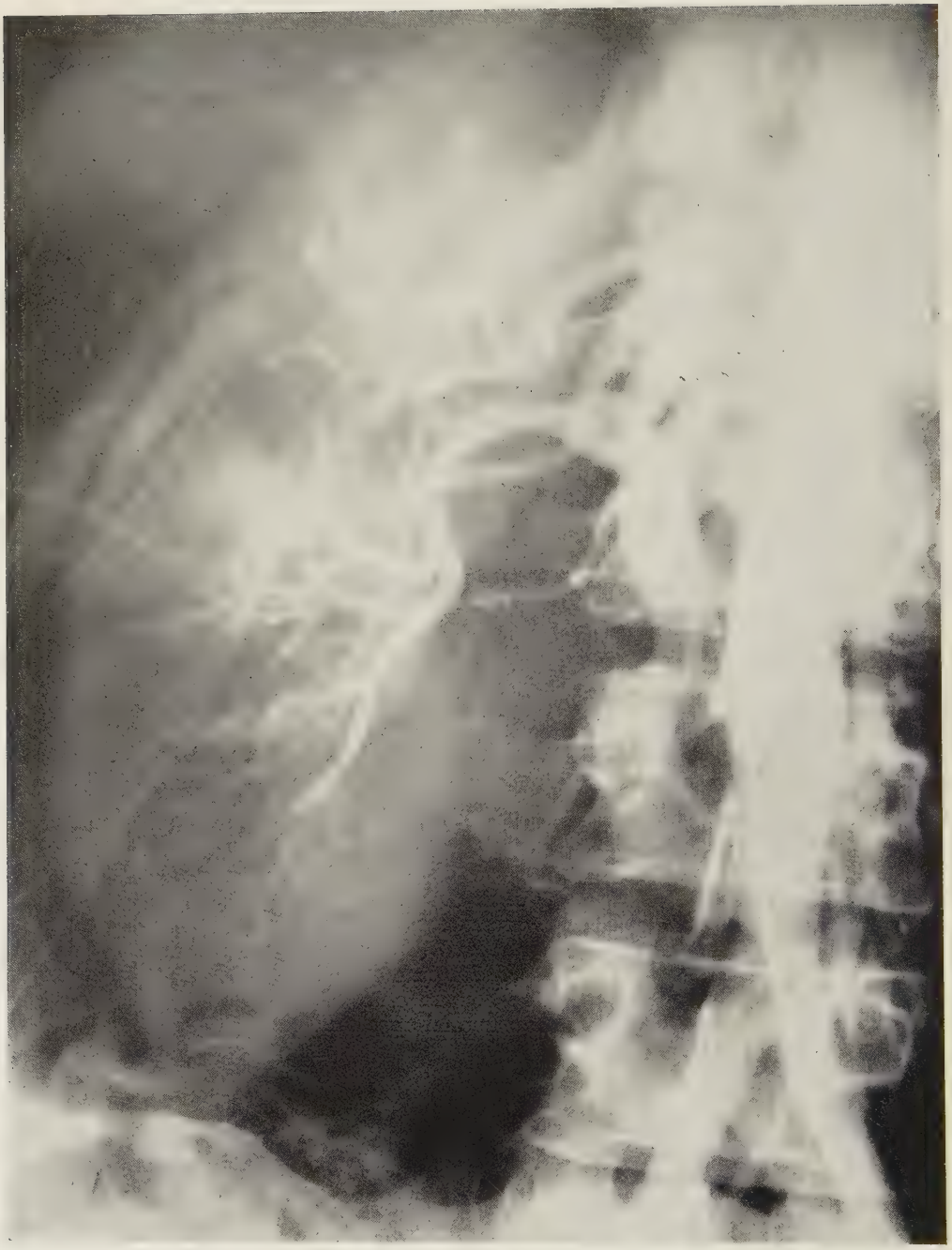


Fig. 61 (above) and Fig. 62 (opposite) show details of two films from an aortography of the kidneys, which was made because of a suspected tumour. Interval 2 seconds. Moving cross-grid as in Figs. 59 and 60. Exposure 0.20 seconds, 110 kV, 150 mA. Catheter was used. The films show normal appearances.

Fig. 62.

tumour. The exposure data were: 0.20 seconds, 110 kV and 150 m A. There was about 2 seconds' interval between the two films. There are no pathological changes visible.

The same cross-grid as used in the examinations discussed above has also been used in my studies of the radiographic depiction of smaller vessels with a micro-densitometer. Such an investigation requires a completely homogeneous radiograph without any grid pattern which may materially disturb the densitometric recordings.

STROBOSCOPIC EFFECTS: VISIBLE GRID PATTERN IN THE FILM CAUSED BY INTERMITTENCE OF THE TUBE CURRENT

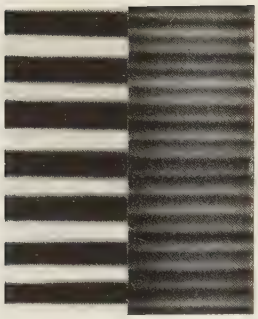
Intermittence of the current supply

The irregularities in illumination which were mentioned in the preceding chapter and due to the particular character of cross-grids, may be wholly eliminated by the selection of a suitable direction of motion of the grid pattern. In this chapter, a review will be given of a completely different type of irregularity in illumination, namely that which may occur by reason of the flow of radiation from the tube not being continuous, but intermittent. These problems may have their application to all kinds of grid motion, both for single and cross-grid systems. With the latter, the case is a more complicated one.

The power supply for radiographic apparatus is usually 50 or 60 cycles alternating current. This current is commonly rectified by a four-valve system producing so-called full-wave rectification. It is less common to use a six-valve system connected to a three-phase supply, though such systems are employed in some hospitals and seem to increase in use. In the four-valve circuit mostly used for diagnostical purposes — the so-called GRAETZ circuit — a 50 cycle current gives 100 marked peaks of voltage and current per second. In three-phase systems, these are more closely spaced and much less distinct.

Particularly in four-valve apparatus, but also to some extent in three-phase installations, the special character of the current supply with pronounced intermittence will give an intermittent flow of radiation. Since it is known that the photographic effect of the radiation is usually proportional to the fourth or fifth power of the voltage, as shown by A. BIERMANN and H. BOLDINGK (1951), and others, as well as in the present investigation, the radiographically effective peak must be very short and pronounced.

A photographic comparison was made between the radiation intermittence with four-valve and six-valve systems. Radiation from a roentgen tube was allowed to pass through a narrow slit in a lead plate. Below this slit was a cassette in rapid motion: about 0.5 m per second. The peaks of the radiation were recorded as heavily exposed lines parallel with the slit. Fig. 63 *a* demonstrates the extremely well-marked peaks of intensity obtained with a four-valve apparatus. The radically more favourable conditions offered by the three-phase current and a six-valve



a *b*

Fig. 63. A photographic comparison between radiation intermittence with four-valve and six-valve systems. A narrow slit has moved rapidly over the film surface letting through the radiation. The four-valve system *a* offers very marked peaks of intensity compared with the six-valve system supplied by three-phase current *b*.

unit of conventional type are shown in Fig. 63 *b*, which was made in the same manner and with a similar cassette speed. In this case only small fluctuations in radiation intensity are recorded. Naturally the tube current graph, and consequently the radiation output, may vary somewhat with the type of apparatus. This is but a typical example.

There are also capacitor units which supply current without intermittence. In these, however, the voltage is not maintained constant during the exposure, but falls. Mention should here be made of the high-frequency generator for roentgen tubes developed by A. Nemet. In 1953, Nemet demonstrated good results obtained with a roentgen unit working on 500 cycles alternating current. The electric parts, by reason of the high frequency, could be made very light, and some purely technical advantages were secured. The apparatus has apparently not yet passed the prototype stage, but it certainly has a future; the principle is fascinating.

Explanation of stroboscopy with grids

The phenomenon produced by intermittent radiation striking a moving object and producing a false impression of its real motion is called stroboscopy. The stroboscopic problems connected with grids will now be discussed, a single parallel grid first being considered.

Every short peak of intensity of the tube radiation, however frequently or rarely it may occur, casts a kind of flash-light shadow of the moving grid onto the film. This shadow is not necessarily sharp and clear. It may be blurred at high speeds, but there is no mistaking its character being that of a grid pattern. The next flash of illumination will also project a similar shadow of the grid on the film. If this projection should coincide precisely in position with the previous image — which, owing to the incomplete exposure, may perhaps be represented only by a very faint latent image in the photographic emulsion — a superimposi-

tion and intensification of the latter will be the result. If the frequency of the current and the speed of the grid are maintained constant during the exposure, the next current impulse may also be expected to produce a similar projection of the grid in a position identical with the preceding one. When the exposure is completed the series of peaks have accumulated similar projections in the same positions and the film shows a characteristic pattern. This is a distinct case of stroboscopic effect.

Selected references

In spite of the undisputable importance of stroboscopic phenomena, the literature on them is rather scanty. A short review of certain works will be justified after the previous theoretical and experimental illustration of the problem.

In 1931 H. Potter discussed the generation of visible lines. He explained it partly by synchronism of pulses from the tube and passage of grid strips over individual points in the film. He also suggested that the beginning and end of the exposure might cause so-called "initial and terminal oscillating effects" and he recommended the use of a special switch mechanism which would give a successive increase and reduction of the current at the beginning and close of the exposure. According to E. F. Flarsheim it would be appropriate to have a rising or falling curve during one-sixth of the period of exposure.

M. F. Block, in 1933, discussed fundamental problems concerning stroboscopy, the shape of the current graph and the way in which synchronism between current peaks and motion produces a visible pattern by repeated projection of the grid.

In 1934, R. Pape discussed the effects of the intermittence of the current in the shape of striping generated by motion of the cassette or by the object, although without entering into the factors connected with the grid. Other forms of striping discussed by Pape in his work, such as a contour striping also mentioned by H. Chantraine and B. Walther (1932) and earlier by Walther (1917), need not be considered here.

A fairly concise review of the problems of stroboscopy was given by F. Facci (1935), although without defining any optimal speeds. The most exhaustive discussion of the problems is that of W. Watson (1936), who outlined the fundamental conditions for homogeneous illumination with different types of grids. He presented interesting diagrams. The minimum motion for complete uniform rendering was analysed and Watson suggested that it would be possible in certain cases to manage with a very short motion if only the grid projections could be placed close to each other until complete coincidence was reached; the dimen-

sion of the grid would then play an important part. WATSON's study of the problem differs from those reported here insofar as he has attempted to calculate the requirements for a pattern-free image with the shortest possible grid motion, whereas in my opinion it is simpler to analyse the premises for full stroboscopy independently of the grid dimensions and at different motions of varying size. It seems to me that in practice longer movements should be used than those recommended by WATSON. The exactness of speed adjustment necessary for the desired result is very important, as shown by WATSON's interesting work.

There is no doubt that factors connected with the current through the tube, as well as its wave form, are of importance; variations may occur in apparatus of the same type. The special electrical characteristics of the tube can affect the current wave form at pulsating voltages and there may also be different wave forms with various transformer constructions. For this reason, various types of tubes will cause a more or less pronounced degree of stroboscopy. K. C. CLARK (1953) emphasized the importance of the shape of the current curve, and a detailed study of this problem is in progress. The varying wave form of the current in tubes of different types has been demonstrated, for instance, by A. BOUWERS, as early as 1929.

Possibilities of stroboscopic pattern formation in the film — an analysis

The conditions which produce stroboscopic phenomena with visible pattern in the radiographic image will be discussed. Fig. 64 demonstrates in a simple manner some possibilities of repeated identical pictures of grid elements in the film. The grid is moving to the right. The interval between two maxima of illumination may be taken as the unit of time, and the arrows indicate the distance covered during this unit of time. When the size of the movement and the distance between the grid elements are equal, we obtain the coincident depiction described above (*a*). It is, however, easy to imagine other conditions under which such coincidence is obtained. At speeds which constitute an aliquot fraction of the speed in *a* this may also occur. In *b* it is equal to one-half. The critical points will be exposed only at every second impulse of illumination. But they will coincide in the same way as before, and a linear pattern is obtained with dimensions which are one-half of those of the grid. One might consider that this image would be of lower density: it is built up by just half the number of light flashes, the number of lines being twice as large. Since the system has moved only at half of its previous speed, however, every single line has become more sharply defined.

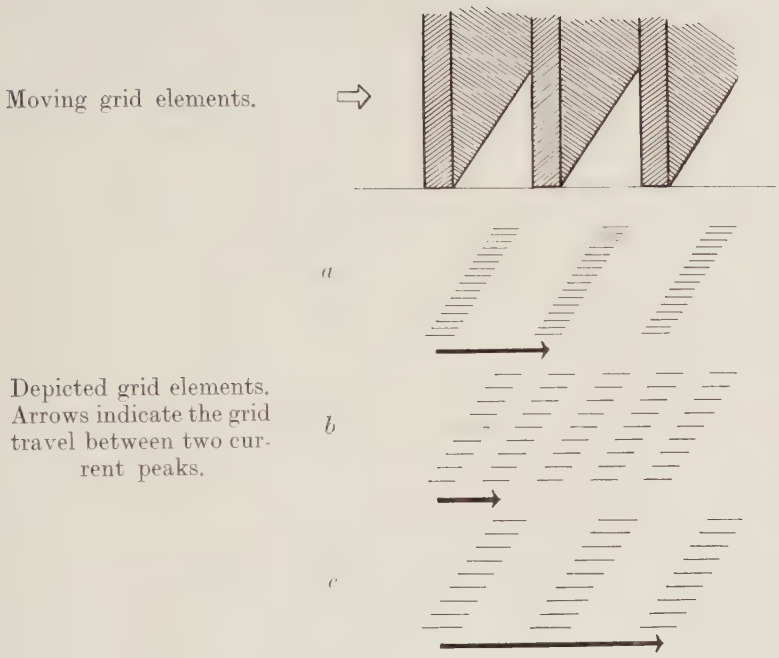


Fig. 64. Some possibilities of stroboscopic phenomena with a grid. *a*, *b* and *c* correspond to different speeds.

At still lower speeds, similar stroboscopic phenomena will reappear, *e. g.* at 1 3 or 1 4 of the original speed. Owing to the shorter distance between the lines and their lower intensity, the importance of the coincident grid structures will decrease.

Inversely, *i. e.* by increasing the speed, coinciding patterns will also be obtained. These, however, appear somewhat less distinctly because the high speed gives a less sharp and more protracted image. In Fig. 64 the double speed is shown in *c*.

The possibilities of stroboscopy may be demonstrated graphically. The mechanism of stroboscopy shall be explained somewhat further from the figures, in order to show how it may be avoided.

In Fig. 65 the rows of points represent the series of recordings which are obtained for each radiation maximum. The individual points represent the recurrent grid elements, *e. g.* the lead strips of the grid. The time interval between the rows is one-half of a cycle, and the movement is assumed to be directed towards the right. At complete synchronism between the motion of grid elements and the current impulses, a parallel travel of the size of a grid bar interval has occurred between two consecutive peaks of the current. The projections of grid elements will, with

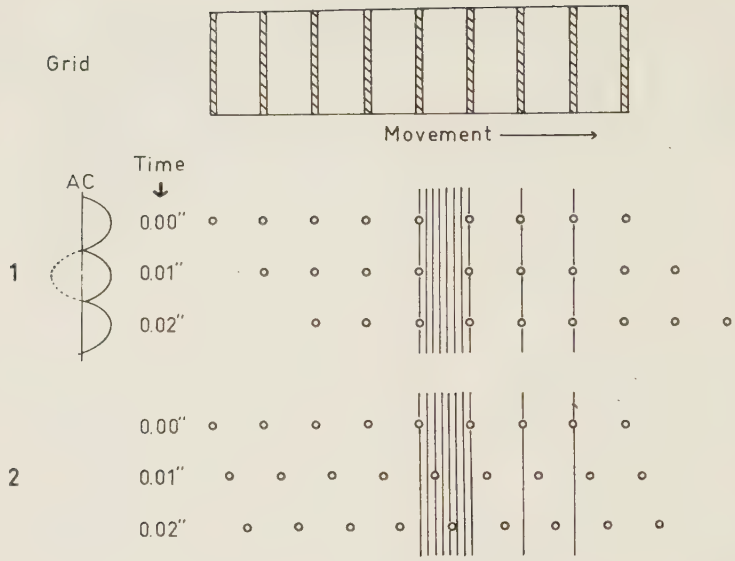


Fig. 65. The grid shown in the upper part of the picture moves towards the right. The depicted grid elements are represented by the rows of points, one for each current peak. The final picture contains a summation of all exposure impressions. This summation can be made vertically along the parallel lines in 1 and 2, which correspond to different speeds.

full synchronism, be located immediately below each other and the aggregate illumination in individual spots of the film be obtained by vertical summation — the vertical lines (case 1). A slower rate of motion would cause a lagging of the pattern so that the points would no longer be located directly below each other (case 2 in Fig. 65). The corresponding phenomenon could of course also occur at a more rapid rate of motion, in which case the points of the lower row would be more advanced towards the right. When summarized vertically, the projections should not in this case show any marked maxima, and thus the stroboscopic effect will be restrained.

The travel of the projections of the grid elements at various speeds may be illustrated by lines, differing in obliqueness according to the respective speeds. The chance of repeated identical recordings, which is the prerequisite for stroboscopic effects, can be studied in a simple way from the system of points below each other, which is similar in design to Fig. 66. If the lines connect points in consequent rows a marked stroboscopic formation will appear. Lines connecting every second and third row represent speeds with stroboscopy of decreasing obviousness.

In this simplified diagram only a small number of current cycles have been included, and only the most obvious cases of stroboscopy can be

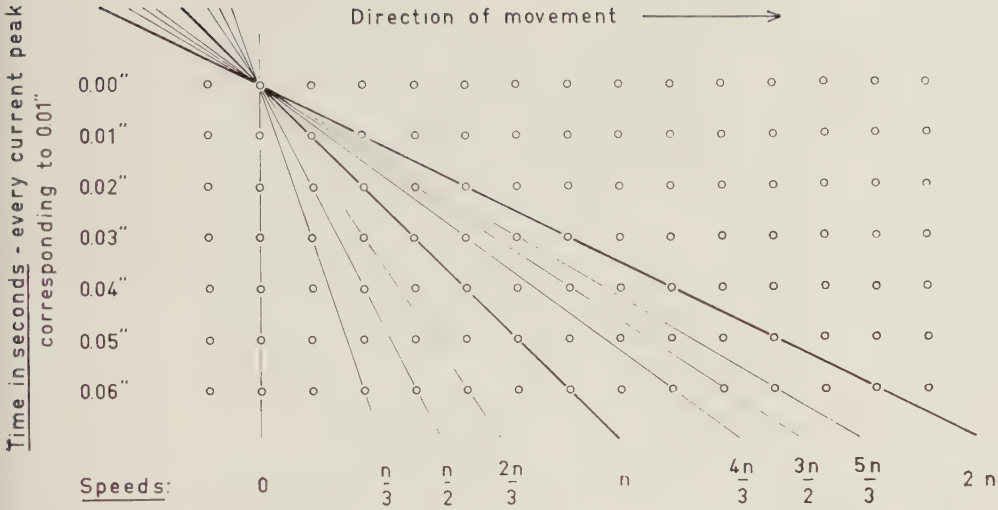


Fig. 66. The stroboscopic effect of varying speeds may be symbolized by lines in a system of rows of points. The superimposition of grid projections which generates stroboscopy is signalled by the passage of a line through a series of points. Each of the oblique lines represents a certain speed, the highest degree of stroboscopy being attained by the lines passing through a point in each consecutive row.

demonstrated, although others of less importance will be possible. The speed 0, *i. e.* the stationary position, is represented by a vertical line, other speeds by lines of varying direction, their relative values being shown below $\left(\frac{n}{3}, \frac{n}{2}, \text{etc.}\right)$. One recognizes values of speeds which have been touched upon previously.

The diagram shows that the 'dangerous' speeds will appear groupwise in series which will be repeated with the variation of speed. It is to be expected that the same serial distribution will also occur at still higher speeds.

The abundant opportunities for stroboscopy to occur are quite surprising. The question is *how to avoid these phenomena*. The only answer is that there are also many methods of avoiding stroboscopy, since one may choose speeds lying between the dangerous ones, which will also appear regularly and will be passed one after another as the speed of the grid is changed. It is immediately evident that the exact adjustment of the speed of the mechanisms is of vital importance. In some experiments, in which the demands on freedom from pattern were increased by the employment of a non-screen technique, the very great importance of speed adjustment was confirmed.

The conditions discussed above apply to single parallel grids of the conventional type. As soon as moving cross-grids are concerned the case

is a more complicated one. Each component system has its own stroboscopy, and the optimum speed for freedom from the phenomenon must be chosen with particular care in order to satisfy the demands for freedom from visible pattern in both systems. In this case it is probable that practical tests are best for the choice of speed.

A more detailed knowledge of the qualities of a grid will, however, provide a certain guidance for the calculation of the suitable speed. The movements of the individual grid systems at a certain speed are easily determined from the angular deviation of the system from the direction of motion. Two somewhat different movements are obtained, a greater and a smaller one. By taking the average of these to represent full stroboscopy, one may often arrive at a good result. Both component speeds are deflected, each in its own direction, from a danger zone. The only proper way of obtaining correct speed adjustment, however, is by purely practical tests.

Apart from the conventional stroboscopic effects described above may be mentioned a peculiar pattern of very fine *moiré*, which sometimes appears with cross-grids. It may be explained by an interference between certain stroboscopic phenomena of each of the combined single systems, which are not themselves visible.

The stroboscopic phenomena which may appear with a cross-grid pattern may be made visible to the eye with unsurpassed clearness in an apparatus specially developed by the author. It consists of a drum on which photographically reproduced grid patterns can be so mounted as to cover its whole circumference. These could be given different degrees of inclination as desired. The drum was rotated round a vertical axis and was driven by an electric motor, which permitted regulation of the speed. Fig. 67 shows the apparatus. By means of an alternating-current driven fluorescent tube with short light impulses synchronous with the current, the flow of radiation from the roentgen tube could be reproduced. This apparatus was the outcome of a series of experiments for the development of a mechanism in which an arbitrary motion could be imparted to a greatly enlarged grid pattern produced by photographical means. For the first tests a stationary grid model was used, while the motion relatively to the eye was produced by a rotating mirror drum.

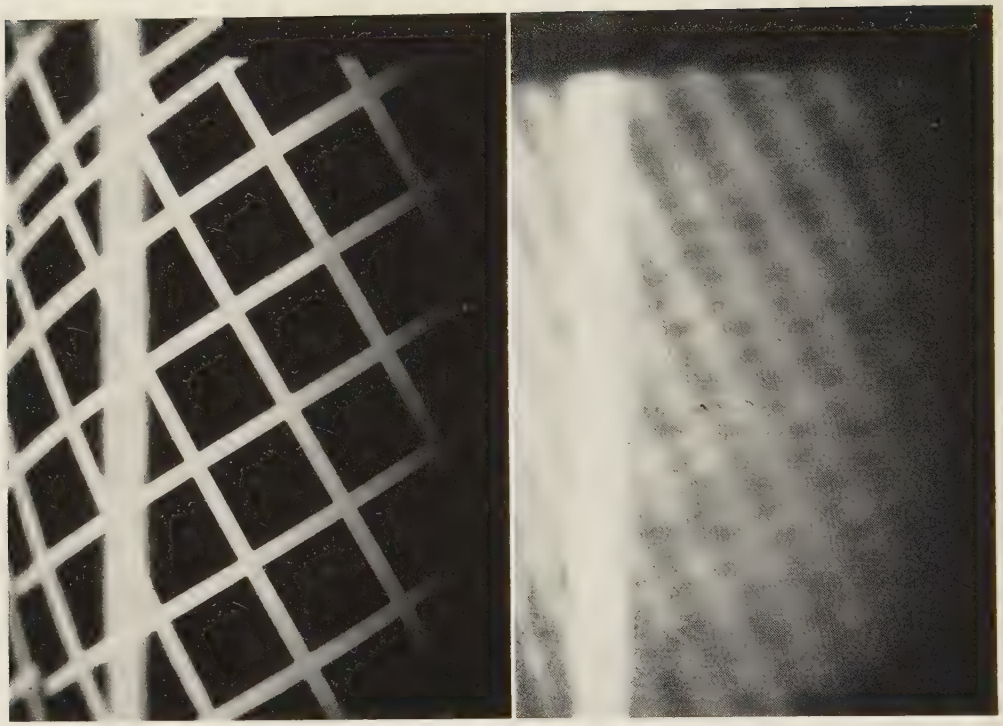
By means of the drum it was possible to study the stroboscopic effect of different speeds. Interference phenomena of a stroboscopic nature were observed practically continuously. The majority of these, however, were of no importance for the photographic image, and could only be observed by the eye. The coinciding grid patterns at full synchronism between grid movement and light impulses are characterized by a *stationary* image of the grid, corresponding to that which is obtained on the film. Variations in speed appear to the eye as movement of the grid pattern on the drum. It may advance or recede, more or less rapidly, owing to the size and direction of the deviation. At varying speeds of the drum

Fig. 67. A rotating drum used to demonstrate the stroboscopic effects with cross-grids. The enlarged grid pattern, which was produced photographically, can be arranged with desired orientation on the cylinder surface. The drum is rotated by a small electric motor.

one may observe how various stationary patterns are interwoven with each other successively, with intermediary floating interferences. For a cross-grid the two linear systems alternate in producing clearly visible stroboscopy. Within the respective zones of speed more or less closely spaced linear patterns are observed.

Fig. 68 *b* demonstrates the appearance of different stroboscopic phenomena: one for each parallel linear pattern. They correspond to different fractions of the interval between the lines as seen on the stationary drum in Fig. 68 *a*. Apparently the speed has been half that of the stroboscopic speed corresponding to full synchronism for one of the line systems since the visible lines are twice as many as the real lines.

With cross-grids, it was also possible to study the effects of varying obliqueness of the grid pattern. In Fig. 68 *b*, a striping parallel with the direction of motion of the drum also appears. This indicates that the obliqueness of the pattern has not been the most suitable one.



a *b*

Fig. 68. An example of stroboscopic effects as produced by intermittent light illuminating the rotating drum. In *a* the pattern is stationary, in *b* it is in motion. For each parallel linear system there appear stroboscopic phenomena in the form of fine patterns. In addition a slight parallel striping is visible, caused by an incorrect direction of motion.

To summarize, moving grids present numerous opportunities of disturbing stroboscopic effects with intermittent radiation. The effect seems to be most pronounced for certain multiples and fractions of the speed, which represents a travel of one grid strip spacing per half-cycle of current and which represents the optimum condition for stroboscopy. Speeds differing upwards and downwards from danger zones should be used, and for cross-grids the speeds should be so chosen that the speeds of the individual grid components satisfy the respective requirements. It is fully evident that a constant speed selectively chosen must be superior to all other kinds of motion.

The use of six-valve three-phase systems instead of four-valve is a very important factor if the tendency of stroboscopic effects is to be reduced.

One of the available possibilities for the reduction of stroboscopic phenomena is to raise the frequency of the current. It is with a certain

interest that one envisages the future progress of the Nemet system of 500 cycle alternating current. Besides other advantages the frequent impulses already with a moderate motion of the grid strongly reduce the chances of pattern-producing synchronism.

Size of the grid movement

A question of primary importance is how far a grid must have time to travel during the exposure. There is a certain divergence of opinion. Watson maintains that, theoretically, a distance equal to the width of only a few grid strips moving across the film would suffice to obtain complete homogeneity of illumination. If so, a compensation would be effected for purely mathematical reasons. This, however, is but a half-truth and without corresponding practical significance. The probability of the illumination beginning and ending with the grid slats exactly in such a position that homogeneous illumination is obtained, is practically nil. As the exposure begins, some parts of the film are shadowed by grid slats. They are accessible to illumination a fraction of a second later, and thus their exposure starts somewhat later than that of other parts of the film. The chances that just these parts will have their illumination. interrupted a corresponding period of time after other regions of the film — a prerequisite for homogeneous illumination — are extremely remote.

For an arbitrary exposure, one must have a total of so many grid element passages over the film that a difference in exposure produced in the manner described would be imperceptible in relation to the total illumination. S. Ledin (1952), departing from values reported by W. Bronkhorst (1927) for the smallest possible difference in blackening perceptible by the eye, maintained that some 30 grid strip passages over each point would be required at a total film density of 1.0. Naturally the photographic technique used may influence the conditions. Furthermore, the size of grid elements seems to be of decisive importance, as well as the radiographic technique in general. Discussing the problems at an earlier stage (1917) A. Lotzin gave much fewer (12 to 15) alternations as a minimum, but made no detailed study of the problem. The arrangement suggested by Potter and Flarsheim (1931) for the successive increase and reduction of the current at the beginning and close of the exposure may here assume certain importance. With today's equipment employing high outputs and short exposures, it is scarcely possible to make such a provision.

With a fairly large movement per unit of time, the recordings of grid elements will be less sharp than with a smaller movement, and possibilities of visible patterns will be correspondingly decreased. As shown

above, the speeds which are situated between danger zones may appear at multiples of lower structure-free speeds. Because of the stroboscopic phenomena, and because of the effects just discussed and connected with the initial irregularity of illumination which can never completely be eliminated in grids, it seems advisable to use a relatively large grid movement.

Grid drive mechanisms — a review of applied principles

When grids moving during the exposure were first introduced, it was not long before an electric motor was employed for the driving mechanism. Many of the earliest drive systems were in fact electrical, particularly when movements of a more continuous nature were concerned. Mechanisms of this type with rotary motion were those of Potter (1917), Å. Åkerlund (1923) and H. S. Sawford (1923, 1924). The grids used were in the shape of revolving discs.

The moving parallel grid system with rectilinear motion described by Potter in 1920 includes a clockwork system actuated by a weight and having an oil drag with a valve in the piston. With the exception of the weight, which was later replaced by a spring, this principle has remained unchanged over a long period. Its characteristics are simplicity and easy regulation. Other mechanisms with clockwork for speed regulation have also been developed, but release and control have been governed by an electric circuit as described at an early stage by E. W. Powell (1923) and P. C. Hodges (1923).

During recent years conventional drive mechanisms have partly given way to new systems which at the same time have found employment where stationary grids were previously used.

Systems using reciprocating or oscillation motion, which require no winding up of the mechanism between each exposure, have found acceptance. I would here refer once more to the foresighted design of Lotzin (1917), which consisted of a reciprocating mechanism with an arrangement for the interruption of the tube current at the extremes of travel. Modern oscillating systems may consist of spring-suspended grids which execute a pendulating motion. A. Keuser (1932) described a spring-suspended grid and found the oscillating motion generated well suited for radiographic purposes. Owing to decreasing deflexion the turning points will change positions constantly (compare Fig. 69 *a*). This implies reduced danger of visible structure in the picture. Watson (1945) used spring leaves bent to an extreme position and then released, whereupon the oscillations continued for a few seconds. These spring-suspended systems may well be used *e. g.* for making radiographs of subjects erect and with a horizontal direction of the rays, where previously only sta-

tionary grids were possible. A screening and radiographic apparatus called the 'Scopograph', described by W. Alberti (1930) but further developed later, contains such a mechanism, the spring of which is set manually and released by a solenoid. A grid mechanism for purely manual operation is mentioned by J. Buckstein (1945), while an oscillating grid with very short range of motion and wholly electromagnetical drive system was constructed by Ledin about 1950. In this case, a vibrating motion is maintained synchronously with the current, and the grid may therefore always be in motion during the moments when the current maxima produce an exposure. Owing to the heavy vibrations, which extended to the surroundings of the mechanism, and to the considerable noise generated, this apparatus never found any practical employment.

Liebel-Flarsheim, U. S. A., now manufacture a drive mechanism for reciprocating motion, with alternating rapid and slow motion. It was built after the directions of P. C. Hodges, and its original transmission was a screw with half-nuts which engaged alternatingly. In the most recent modification, the rapid motion is produced by a solenoid, while the other, slow motion is generated by a spring with a damper.

A mechanism built in England by Philips Ltd. gives reciprocating swinging motion produced by an electric motor. Six passages per second are said to be possible. The total range of movement is about two inches, and an eccentric mechanism is used. An apparatus developed quite recently by Siemens uses a varying speed, which reaches its maximum at the start and then slows down. Without special readjustment this mechanism would seem to be suited for both long and short times of exposure. The motion is generated by a spring which has to be set and is regulated by an oil damper of special design.

A Swedish experimental model (Elema) is adapted for use vertically with erect patients (in Forsell's equipment). It has a cam drive which permits a very high speed.

For angiography, which is one of the most important fields of high-voltage technique, rapid change of films is essential. This lays particular claims on the grid drive mechanism. The rapid sequence of exposures requires facilities for practically continuous operation of the mechanism. Oscillating or reciprocating systems seem to offer advantages but have also important disadvantages. They can work quite independently of the other apparatus, and the exposure may be made at an arbitrary moment. Sometimes there is a synchronizing of the exposure to the motion making the exposure start at a suitable moment so that turnings are avoided. Because of the mass of the grids, which are often quite heavy, acceleration and retardation of the swinging motion cannot be instantaneous, and undesired speed variations may therefore occur. The turning, when the grid is stationary for an instant, may be a source of grid

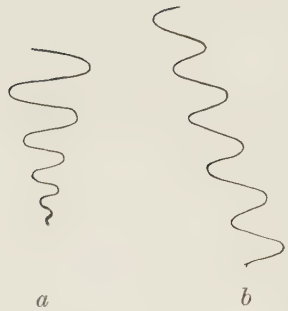


Fig. 69. The motion of an oscillating grid, illustrating opportunities of reducing the effect produced by the turning points, which change their positions during the course of the motion. In *a* there is a continuous change in amplitude, in *b* a gradual dislocation of the whole mechanism.

pattern as many exposures, because of their length, include at least one turning. If repeated turnings cannot be avoided, their detrimental effect may be reduced by changing the turning points continually, either by a continual change in amplitude, or by a gradual displacement of the whole mechanism (see Fig. 69 *a* and *b*). With regard to the risk of visible pattern, especially with heavier grids, both varying speed and turnings during exposure, however, must be avoided.

Such apparatus as requires setting or any manual operation between each exposure, such as settling down the grid to a starting position by reverse travel, cannot be considered to satisfy modern demands.

A graphical study of the motion of different grid mechanisms

As the problem of speed and speed adjustment seems to be of dominant importance, it is of value to study the qualities of different grid mechanisms in this respect. A small registering apparatus constructed according to Fig. 70 was used. The motion of the grid frame was transferred to a pencil sketching a curve on a moving strip of paper. A clockwork mechanism acting on a roller produced the motion of the paper and a very constant speed was obtained. The transmission system gave a suitable reduction of the motion so that a proper amplitude of the pencil was obtained.

A selection of the graphic recordings is reproduced in Figs. 71 to 75. In the first two figures are shown the curves for some conventional Potter-Bucky mechanisms with oil-drag and spring. Older and modern ones (Schönander) are represented. Different speed settings were used. A straight course of the curves indicated a uniform speed. The very steep slope in the latter curves indicates a very high speed. At the end of the motion an irregularity of the curve is visible, which in all probability is caused by a vibration in the mechanism. It seems to be more marked with higher speeds, but is of no radiographic importance as the exposure is already finished when it appears.

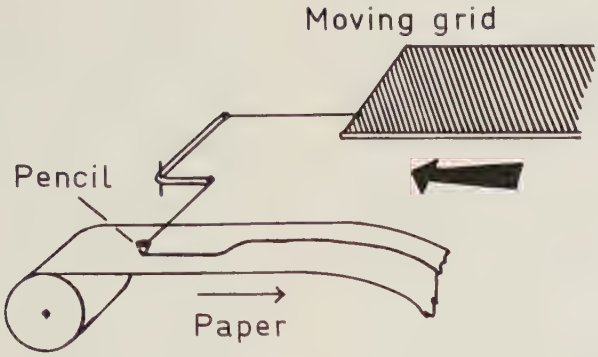


Fig. 70. The apparatus used for registering the motion of grids of different mechanisms. The motion is transferred to a pencil sketching a curve on a moving strip of paper. (Built by G. Schönander.)

A mechanism with varying speed, high at the start and then slowing down (Siemens) shows the graph of motion demonstrated in Fig. 73. It is obvious that the curve has its steepest region in the beginning, where it is practically straight but the speed is not very high. Later on the speed decreases continuously. A very slow speed is maintained during some seconds. This design does not need any special adjustment of speed and cannot be changed to any other type or size of motion.

Some different mechanisms with reciprocating motion were studied graphically. A construction with regular pendulating motion (Philips of England) shows the graph of motion demonstrated in Fig. 74 (bottom). There is a wave-shaped curve, in which some parts are fairly straight, although the general character corresponds to that of a sinus shape. The turning points, which are included in exposure as soon as this involves more than a certain fraction of a second, mean an inevitable standstill.

An experimental type of mechanism (Elema, Sweden) has been tested, and the curve of motion is shown in Fig. 74 (top). It is an arrangement designed for chest radiography and all examinations of erect patients. The grid is moved up and down by a special cam mechanism. The slowly raising part of the curve is straight, the fall is very steep but the amplitude is fairly small. The slight final irregularities are fairly distinct.

Another reciprocating mechanism with continuous operation (Liebel-Flarsheim) has a rapid and slow motion, which alternate. Fig. 75 shows the course of motion. The initial rapid motion of the cycle is fairly slow compared with some high-speed motions shown above. The rapid speed is about 5 times that of the slow one. The turning between the two phases means a temporary stand-still. No remarkable irregularities are observed in these curves, which might be explained by a dynamically well-balanced construction.

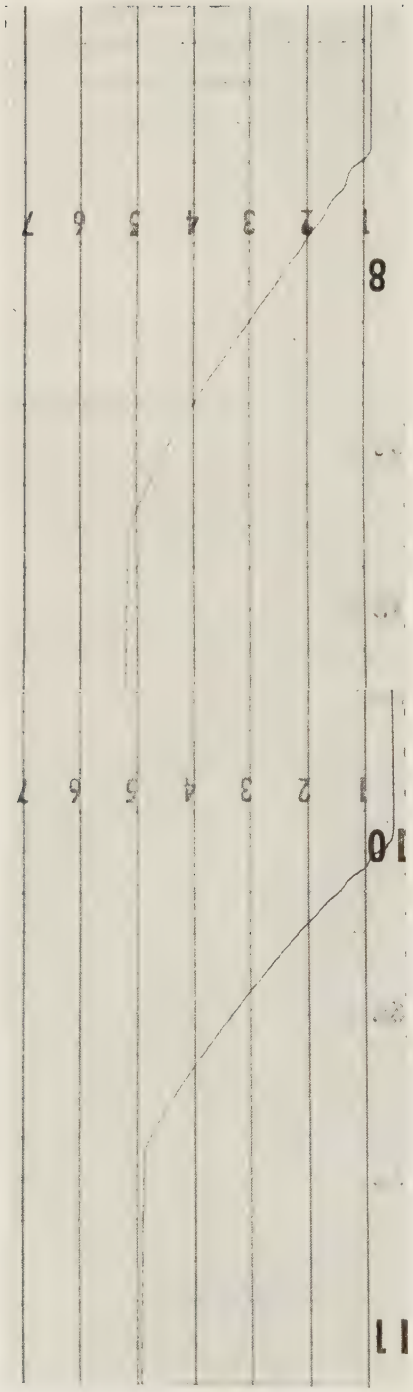


Fig. 71.

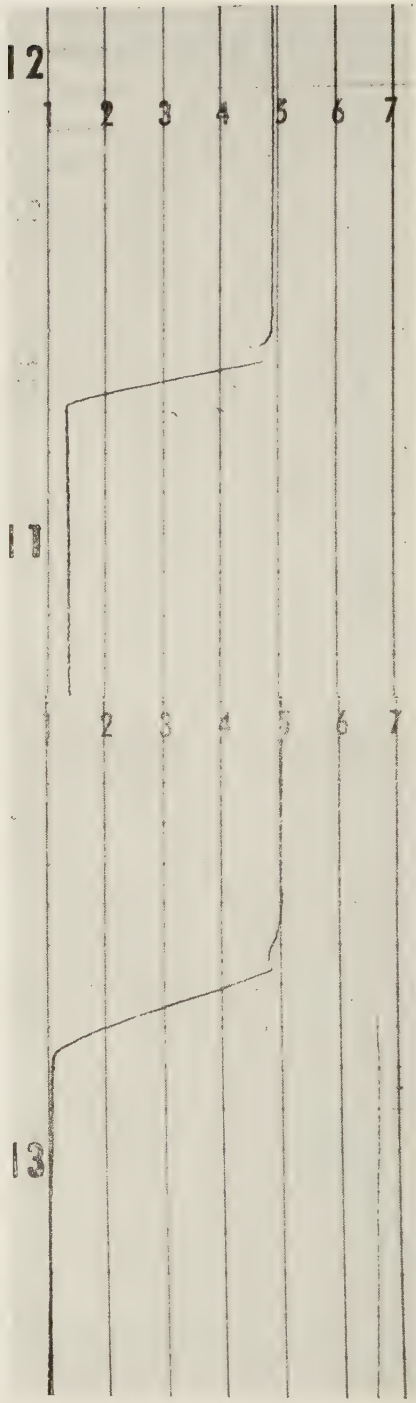


Fig. 72.

Fig. 73.

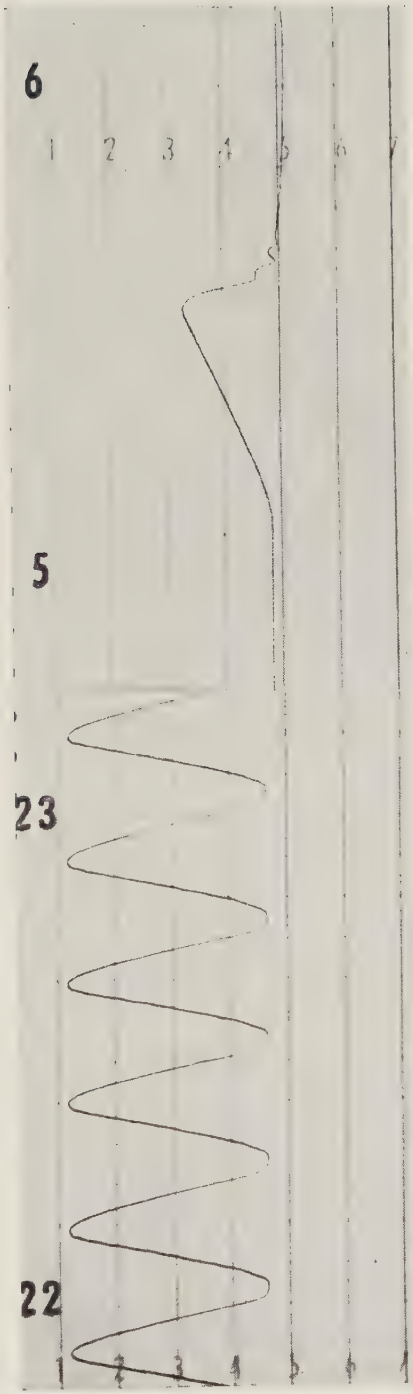


Fig. 74.

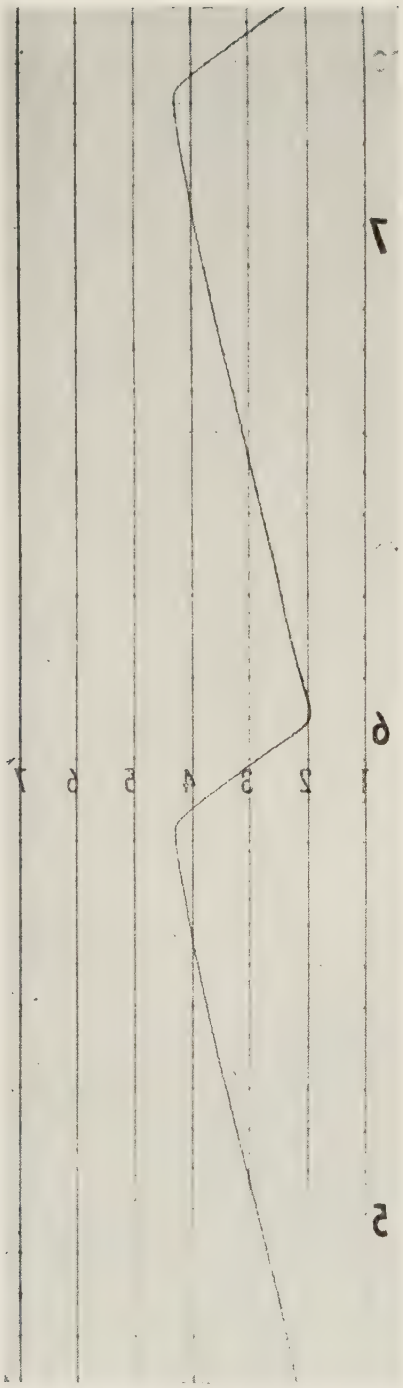


Fig. 75.

Amplitude in centimetres,
Figs. 71—75.

Figs. 71 to 75 illustrate the character of motion of some available grid mechanisms. The graphs should be read from the bottom upwards. Graphs 71 and 72: Potter-Bucky mechanisms of conventional type (Schönander). Graph 73: A mechanism with continuously decreasing speed (Siemens). Graph 74: Two different reciprocating mechanisms. One with a regular pendulating motion, the other with a slow and a very quick stroke (Elema). Graph 75: A pendulating motion with alternatingly slow and rapid speeds (Liebel-Flarsheim).

The length of the line represents 1 second in Figs. 71—75.

Comparisons were made between the appearance of the radiographs with regard to visible grid pattern and the type of motion of the respective mechanisms. Partly single grids were used, partly tests made with both single and crossed grids. Both cassettes and non-screen film was tested. The experiences, which confirm the theories earlier discussed, will be presented next.

Conclusions. An 'ideal' construction

On the basis of theoretical discussion and experiments together with experiences from the comparative practical studies of different grid mechanisms the following general aspects will be presented.

The *character of the current* exercises an important influence. Six-valve three-phase systems with minor alterations in the amplitude of the current graph are superior to the four-valve systems.

The *speed of the grid* should preferably be constant, in order to avoid dangerous speeds. This seems to be especially important for short exposures. A speed which is continuously varying will pass through unsuitable regions of speeds and will be inferior to a suitably adjusted constant speed.

The *size of the motion* during the exposure should be large enough to allow a sufficient number of grid element passages. A higher speed might produce a less sharp recording of the grid elements. With regard to very short exposures, which with four-valve equipment may include only a very few current peaks, the problem of eliminating inhomogeneous illumination is a most difficult one. The only possibility is to increase the speed up to a level where the grid depictions will be highly blurred and the visual impression of pattern consequently reduced. For exposures comprising only one single peak of current, a high speed will be the only factor besides the size of the grid which can influence the impression of pattern to the eye. In that way it has proved possible to obtain a satisfactory film with only one single current peak of a four-valve system. A detail of a chest radiograph exposed with a very rapidly moving grid is shown in Fig. 76. Exposure time was 0.01 seconds, effective exposure because of the current graph only 0.004 seconds. Note the complete freedom from grid structure.

Reciprocating systems imply a considerable danger of visible pattern as soon as the exposure involves a turning point. The heavy masses will be at rest still for a short moment and a pattern will very easily be visible.

The *subjective impression* of stroboscopic effects is influenced by many factors. The size of the grid elements may play a particularly important

Fig. 76. Detail of a chest radiograph exposed with a very rapidly moving grid. Exposure 0.01 seconds, about 250 mA, 150 kV. Effective exposure because of the current graph was 0.004 seconds! (Single Siemens grid, ratio 8 : 1. Motion as shown in Fig. 74, upper curve, rapid stroke.)

part. The level of density is of some importance. It is often noticeable that the pattern is only visible in certain regions with a fixed level of density, but cannot be recognized in thinner or denser regions. This fact may be explained partly by the special character of the photographic material, especially with regard to the density curve, and partly by physiological factors connected with the viewing. An increased contrast, *e. g.* produced by an energetic developer, is favourable for the appearance of a pattern.

The character of the radiographic image is also of importance. Larger areas with small differences in density, such as soft tissues, are favourable for the appearance of visible grid structures, while areas with a richness of radiographic detail restrain the impression of pattern. The use of very rapid and low-definition screens reduces definition of all details, naturally also those emanating from the grid.

The presence or absence of visible pattern is very strongly subjectively coloured and is dependent on a series of different factors. A study of the problem like this one cannot give anything but a general orientation.

From theoretical considerations and practical experience the principles of an '*ideal*' construction, suited for grids of all kinds, will be discussed and outlined.

The well-known conventional oil-damper drive mechanism seems to have many valuable qualities. The speed is maintained fairly constant and can be varied continuously. The great disadvantage has been the necessity of setting the spring mechanism between each operation. If the motion could be made to act in both directions without changing its characteristics, this would be a good solution of the problem of motion, as well as making rapid film changes possible. After a single-stroke operation the mechanism would be ready immediately for the next exposure. Acceleration and retardation are of little importance as the exposure is made during a period of constant speed. The ordinary spring drive cannot be used with such a two-directional motion; either electric or pneumatic operation appears to be the method of choice.

The principle described seems to combine the simplicity of the well-known spring-driven Potter-Bucky systems with some of the advantages of the reciprocating systems, such as facilities for frequent film changes. Its alternating double-motion is designed to prepare it for further action immediately after each exposure, without time-consuming setting of springs or return travel. During the exposure the speed is maintained constant and a standstill of the grid will never occur during that important period. By means of practical tests, suitable speeds for the grid in use may be found for all imaginable exposure times. It is probable

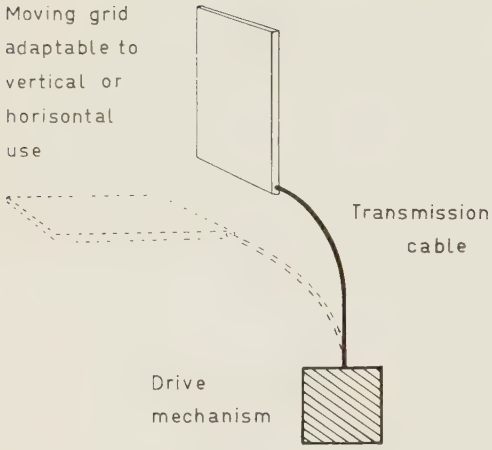


Fig. 77. Principal layout of a grid mechanism easily adaptable for different radiographic purposes. The separate grid housing, being very thin, is connected with the drive mechanism by a flexible transmission cable.

that only very few fixed speeds are necessary. The setting of grid speeds could then be synchronized by electrical means with the setting of exposure time on the control table. No mistakes would then be possible.

As regards the construction as a whole, many modifications of the conventional principles seem to be justified. The grid mechanism ought to be capable of being used vertically, horizontally, or in any position desired.

These demands necessitate a special suspension of the grid frame. A balancing of the grid with a counter-weight is then absolutely necessary. For a cross-grid system, the use of two separate specially adjusted single grids, which have reciprocal motion against each other and thus act as their own counterweights, seems to be very suitable. Compare above, page 112. The mechanism will then not be too heavy since separate weights are not necessary.

The advantages of a very thin and handy grid drive mechanism have been made evident through the experimental investigations carried out with different types of apparatus. The apparatus must be easily adaptable to any cassette or film changer as well as for ordinary radiographic purposes. It seems then to be preferable to separate the drive mechanism proper from the grid frame and its housing, using a kind of cable for the transmission of the power impulses. The grid housing may then be made very thin. The principle is outlined in Fig. 77. It might be employed with either a purely electric drive or a pneumatic system.

SOME FACTORS WHICH INFLUENCE THE QUALITY OF THE RADIOGRAPHIC IMAGE

Since the question of contrast is of fundamental importance in high-voltage technique, it may be justified to consider certain phenomena which have a disturbing effect on the resultant film and which are seldom discussed. These include *'off-focus' radiation* and the problem of secondary radiation from irrelevant objects in the immediate neighbourhood of the photographic material, above all *backscatter*. These two phenomena are similar in one respect. They produce an undesired radiation, which is added to the true image-forming primary radiation and, like the secondary radiation from the object, will impair the picture quality. As will be shown the amounts of this radiation in these cases are not particularly large, but in view of the low contrasts characteristic of the high-voltage technique, from which one wants to obtain the best possible results, these small amounts may also be of importance. These phenomena should not be neglected in discussing further means of improving the radiographic image. Although each preventive measure will cause merely minor improvement, the total effect will be a marked increase in the quality of the film and increased diagnostic possibilities.

THE OFF-FOCUS RADIATION

Introduction

In making an exposure with an ordinary primary diaphragm with a small aperture, it is quite common to find blackening outside the picture field projected by the diaphragm. Frequently this is not only a diffuse blackening; details of the object are usually visible, although with a certain reduction in sharpness. Fig. 78 shows a frontal view of a spine with the usual degree of diaphragming. A fair amount of detail is visible outside the edges of the diaphragm aperture. That these details are not derived from radiation penetrating the lead shutters is shown by the simple fact that no image whatsoever was produced on closing the shutters completely; in this case the shutters could be continuously varied. Exactly the same exposure was made with the diaphragm closed in the

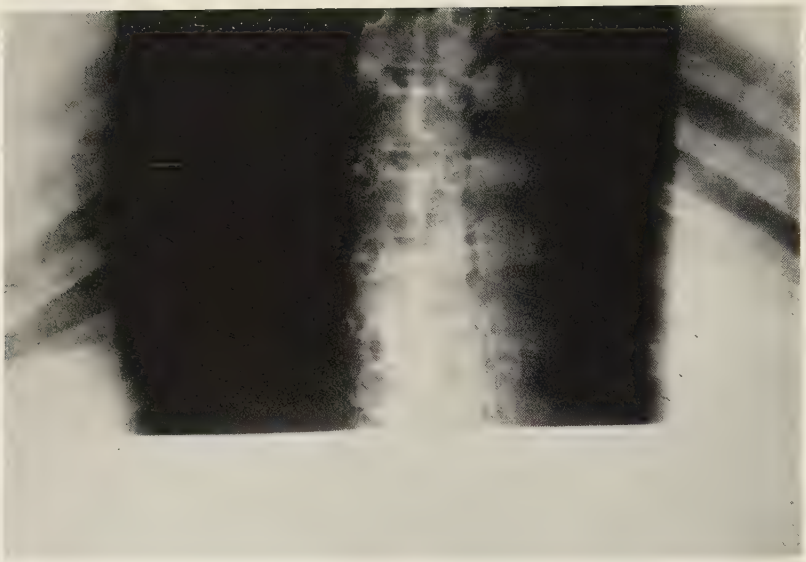


Fig. 78. Frontal view of a thoracic spine with details of ribs visible outside the picture field projected by the primary diaphragm. This depiction is produced by *off-focus* radiation. A similar exposure with the diaphragm shutters closed gives no blackening (the area indicated by an arrow).

lower half of Fig. 78, which shows a film without any suggestion of blackening.

The blackening extending outside the picture field produced by the diaphragm, has also a characteristic spread with a marked distribution in a certain direction. This fact is shown in Fig. 79. There is a band-shaped distribution; the width of the band seems to be approximately equal to the size of the projected illuminated opening. The longitudinal axis of the area of radiation spread appears to run perpendicularly to the longitudinal axis of the tube. For smaller diaphragms this distribution of rays will be more sharply defined in the manner described; for larger diaphragm apertures a more diffuse distribution is obtained.

The effect described, *i. e.* the appearance of an image outside the irradiated surface given by the frame of the diaphragm proper is due to radiation produced by the side of the focus in the tube, which may of course irradiate the object and the film in regions where the focus itself is shadowed by the diaphragm. At the same time, it has the disadvantage of producing an illumination where the focus alone should be the source of radiation. This extra-focal radiation has long been known, and has been discussed by several authors. There is some difference in opinion as to the conception of 'off-focus' or 'extra-focal' radiation. The term

Fig. 79. A typical band-shaped distribution of the *off-focus* radiation is remarkable with smaller diaphragms, here shown in a radiograph of a wrist.

should really be reserved for the radiation produced inside the tube by secondary electron emission. Most authors, however, use it for all kinds of radiation emanating from the tube, except that from the focus itself. Secondary radiation from the oil in the hood and from other external parts is also included; it does not seem so important to distinguish between the different kinds here, especially since the radiation from the interior metal parts predominates in ordinary diagnostic tubes. Since the effect of all sorts of picture-disturbing radiation increases with the special conditions prevailing with high-voltage technique, with its reduction in picture contrast, the problem of off-focus radiation has been considered in this connection. A survey of some previous research may be justified before reporting the results of certain investigations.

A survey of the literature

Off-focus radiation is a phenomenon well-known since the earliest types of roentgen tubes. It is mentioned, more or less briefly, in the fundamental works on radiology, by H. Albers-Schönberg, and others. The information available is associated with the older types of tubes, and one finds terms such as stem radiation and glass radiation. In a diaphragm designed by O. Pasche (1903), a certain reduction of the off-focus radiation was obtained, besides a reduction of secondary radia-

tion from the object. Lead plates with narrow slits were used, which moved during the exposure between the tube and the object and between the object and the photographic plate, so that narrow bundles of rays were made to pass over the latter. This principle has been previously mentioned in connection with different grid constructions.

Among other better known attempts to reduce this undesirable radiation may be mentioned the method devised by H. Potter (1917), which involved the use of a grid-shaped system of lead strips placed on edge between the tube and the object. These strips were specially arranged so as to permit only the passage of radiation emanating from the focus proper. These early attempts, which only dealt with extra-focal radiation, subsequently developed into the construction of the secondary diaphragm between the object and the photographic material for the purpose of reducing the secondary radiation of the former. Early constructions of tubular primary diaphragms, such as that of Albers-Schönberg, aimed not only at the reduction of this non-focal radiation from the tube, but also at a screening of the primary bundle of rays. There are plenty of descriptions of the problems connected with these so-called gas tubes, some of which also referred to the off-focus radiation. Most of them are now of no great value. On the subject of the hot cathode tubes, there is a rather interesting literature, but the problems did not become of vital interest until about 1930. A. Bouwers (1929), in describing so-called self-protecting tubes with a metal shield around the central part, discussed the stem radiation. This would be about 200 times weaker and also softer than the pure focal radiation. With the new type of tube with the metal shield, the stem radiation would to a certain degree be reduced. Pin-hole photographs of the anode show the difference from earlier tubes completely of glass. Bouwers pointed out the importance of this fact for the picture quality. This tube may be considered as a stage of development between the primary open tubes and those completely enclosed in metal hoods. By limiting the radiation by a window in the metal shield, large parts of the inside of the tube were screened off. A. Bouwers and J. H. van Tuuk (1932) discussed the paths and the range of the secondary electrons in the tubes, being the predominating cause of off-focal radiation. These electrons emanate from the focus and appear when the rapidly moving electrons from the cathode impinge upon it. They follow different courses which are curved and of parabolic shape with varying angles of elevation, the electrons seeking their goal in all directions, inside the tube, on the disc and its spindle, etc. The rotation of the disc is also said to influence the shape of the electron courses. Secondary radiation from the interior of the tube may produce a certain amount of tertiary radiation from the tungsten

plate, which, in conjunction with the other emissions mentioned gives rise to the typical distribution of the rays.

P. C. Hodges (1934) reported on results obtained with a focal-spot camera of his own design, using the pin-hole principle, but with holes of varying size situated in a specific manner. With this camera it was possible to make certain measurements, as well as to study ectopic emission in a suitable way.

R. Thoraeus (1937) made comprehensive investigations on off-focus radiation for various roentgen tubes and pointed out that tube parts containing elements of high atomic numbers are particularly active in the emission of off-focus radiation. Tungsten, from which the anode is made, is such an element, and the construction of the tube may therefore influence the quantity of off-focus radiation. Thoraeus stated that roentgen tubes without any off-focus radiation would be the ideal, especially in radiographic work. In a study of different tubes he demonstrated the influence of the aperture upon the quantity of the undesired radiation and made the statement that the amount of off-focus radiation is practically independent of tube voltage and also of filtering, if filters of relatively great thicknesses are excluded. The quantity of this radiation compared with that of the primary beam amounts to 9 up to 25 %, but may be expected to increase in cases of oil-immersed tubes. These values refer to a maximum aperture.

Thoraeus' work seems to be fundamental since the essential facts about off-focus radiation are explored and discussed. Its importance for the radiographic picture, which he pointed out, was not so closely known at that time, and it is a regrettable fact that present-day designers of roentgen equipments appear to take but slight interest in this problem. The difference between the maximal possibilities of preventing the off-focus radiation and those used in ordinary standard equipments will be discussed later.

L. Mallet and R. Maurin, in 1947, made a study of the quality and origin of parasitic radiation from the target of a roentgen tube. This study concentrated on the focal plate proper, and the authors were able to verify the existence of various zones on this plate produced with varying emission. A region next to the focus emits radiation which should have a strength 200 times lower than the focal radiation itself. Around this region there is a zone with still lower radiation although it is larger. The authors also state that there is a varying hardness of radiation with an increasing half-value layer more peripherally from the focus.

The works quoted seem to be the most important ones as regards the intensity and distribution of off-focus radiation. These questions have not been much discussed in the recent literature although their importance has increased.

Studies of certain modern tubes

There are no up-to-date studies of the starting points and the distribution of the off-focus radiation of the modern types of tubes with comparatively large rotary anodes. Since the whole of the anode, which is ordinarily made of tungsten, will function as the source of this radiation, one must consider its importance in relation to the extremely large anode discs, which are an outcome of the latest progress. To quote an example, a recent design, a Mullard tube manufactured in England, has a disc 120 mm in size. Reference may be made to the statement by THORAEUS regarding the activity of heavier elements, *e. g.* tungsten, in emitting secondary radiation.

I used a pin-hole camera to study a series of modern tubes from different manufacturers. The tubes were fitted into different hoods with some different types of primary diaphragming equipments. In order to obtain a picture of the focus and its surroundings, adequate for practical study, the photographic exposures were made at a distance from the tube, which was equal to the normal distance of exposure. To make the

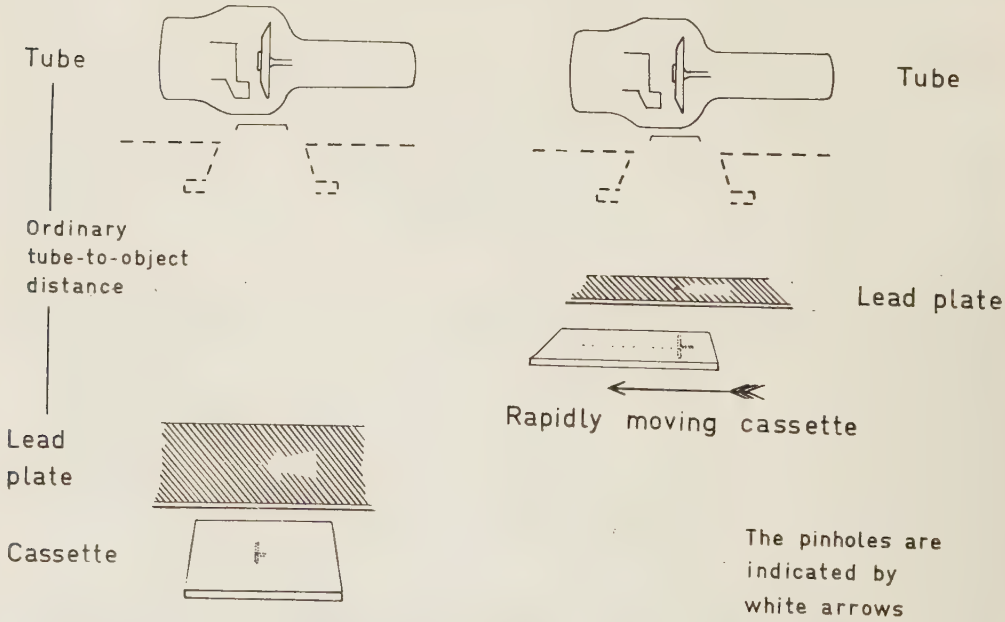


Fig. 80. Experimental arrangements for pin-hole photography of the focal region. To the left: stationary cassette, with the pin-hole plate placed as an ordinary object; to the right: moving cassette, with pin-hole plate close to the tube.

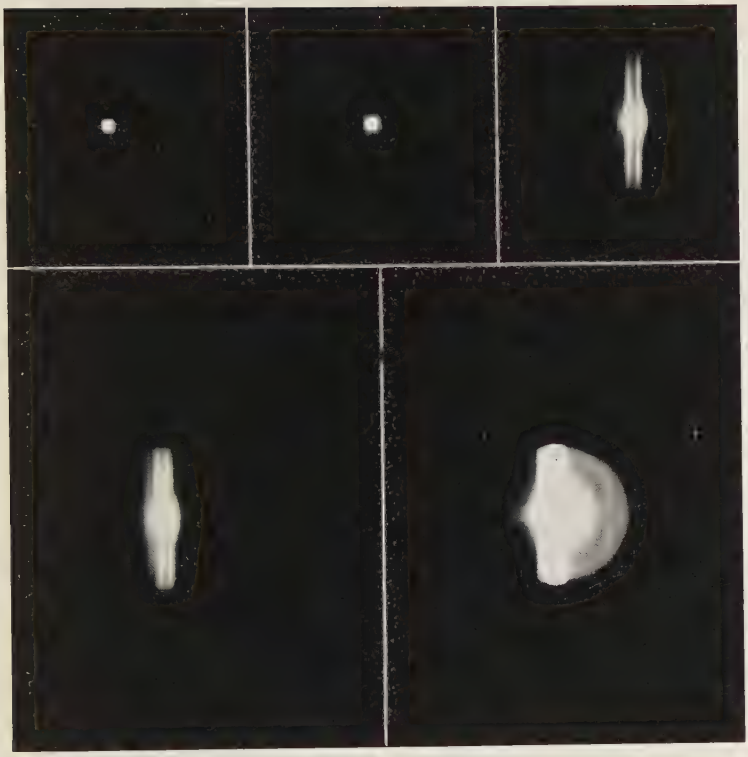


Fig. 81. Pin-hole photographs of the focal region. Effect of gradually increasing exposure (*a*—*e*).

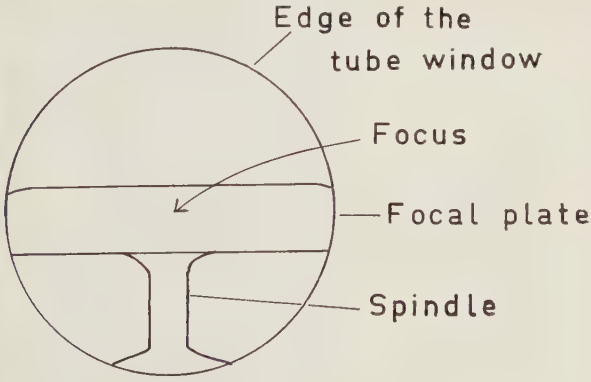


Fig. 82 *a* and *b*. A magnified pin-hole photograph of the focal region with an explanatory sketch to the right.

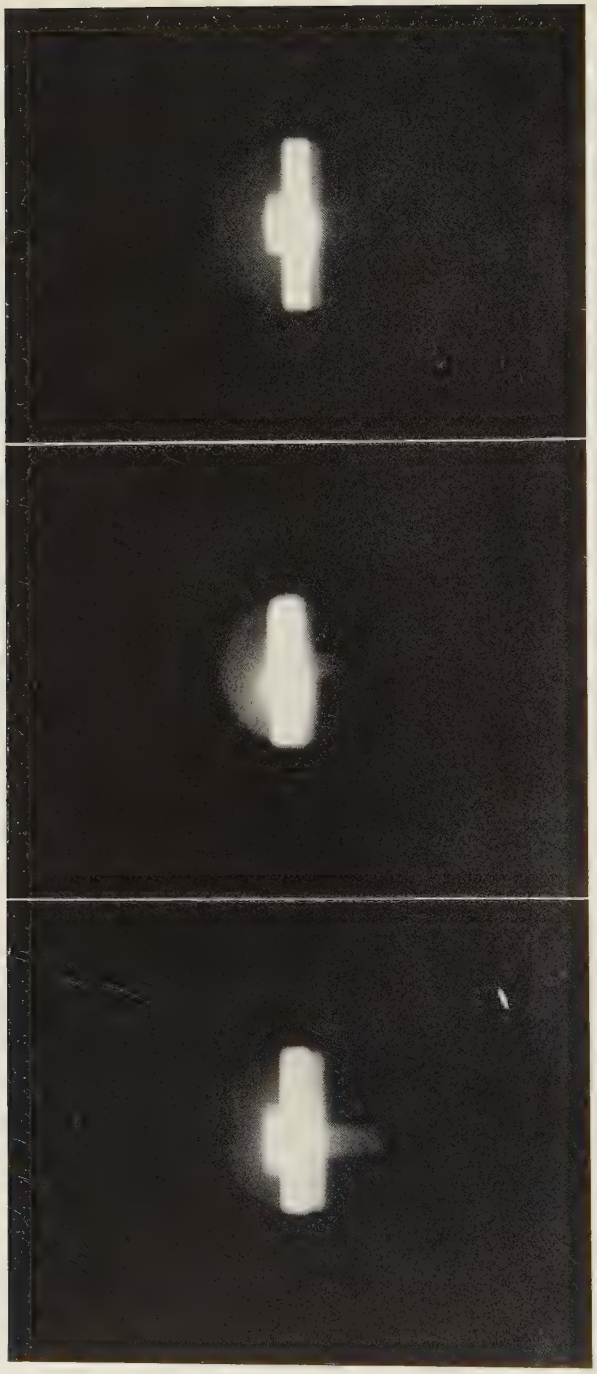


Fig. 83.

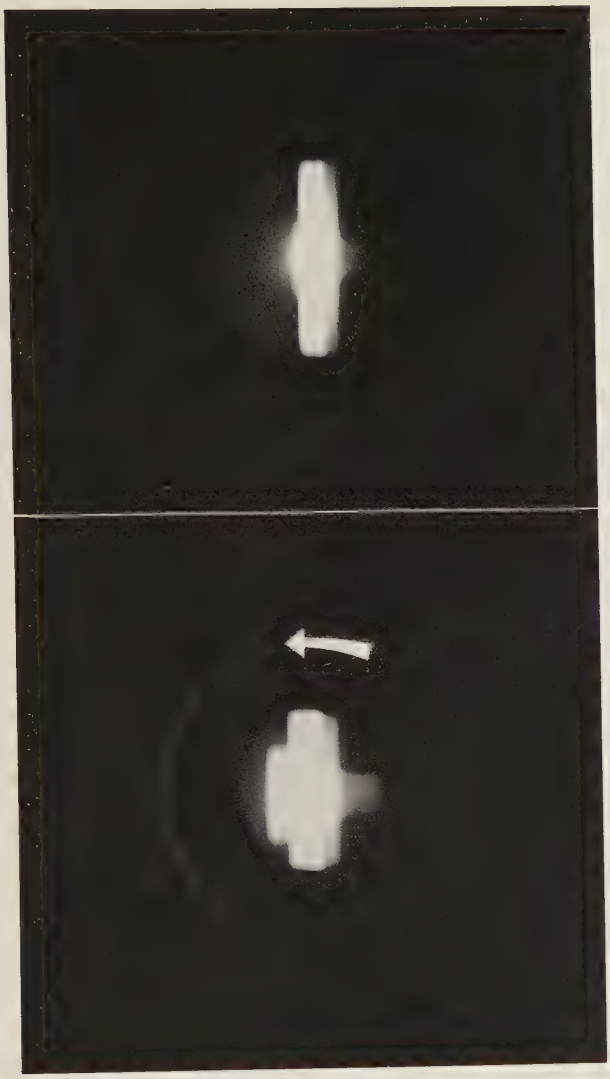


Fig. 83 *a*–*e* (opposite and above). Pin-hole photographs of the focal region of 5 tubes with hoods and diaphragming equipments of different types. *a* and *b*: slit diaphragms (Philips and Schönander tubes, respectively). *c* and *d*: continuously variable diaphragming equipments with multiple planes (Siemens and Philips tubes, respectively). *e*: a slit diaphragm (Machlett tube). Generally, no emission is visible outside the tube window. The slight streak in *e*, indicated by an arrow, is rather unique.

distribution of rays as a whole accessible to study, the primary diaphragms were adjusted to maximum aperture. The pin-hole had a diameter of 0.6 mm. An opening of this relatively large size will of course not permit a very sharp image, but in return a greater brightness of the projected image will be obtained, *i. e.* it will be easier to observe the extrafocal radiation without the exposure times being too long. The pin-hole allowed photographic recordings with a sufficiently wide angle of view. The experimental arrangement is shown in Fig. 80 to the left, while experiments with a moving cassette later on described were made according to the drawing on the right.

The effect of varying exposure is shown in Fig. 81. It will be seen that the shortest time of exposure (*a*) makes only the focus proper visible while other sources of radiation are not depicted. Longer exposures give an increasingly apparent focal disc (*c*), the spindle of which gradually appears together with a more homogeneous irradiation situated mainly on the cathode side (*e*). The round circular contour represents the tube window. Fig. 82 *a* and *b* shows a magnified pin-hole photograph supplemented by an explanatory sketch. With the exposure used in the latter cases all sources of undesired radiation of any importance, also outside the tube, would be depicted. All pin-hole photographs were made around 100 kV.

An examination of a series of different tubes with this camera was made and a selection of the results is presented in Fig. 83 *a*—*e*. The pictures are principally similar, with a typical distribution of radiation. It must be emphasized that the off-focus radiation also with a relatively moderate intensity would be very important as the surface from which it is emitted is so large compared with the focus. Considering the very high intensity of the exposure, it is astonishing that so little detail apart from that of the tube itself is visible; one might expect to find parts of the cone or the frame of the primary diaphragm depicted by their own secondary radiation. But, in practice, this is not the case. The slight streak, which is marked by an arrow in Fig. 83 *e*, is unique but is of no practical importance for the radiographic depiction. It should be especially noted that the primary diaphragm was removed or adjusted for maximum opening and that the metal parts mentioned were in the path of the rays. Different tube hoods and diaphragming equipments were fixed to the tubes examined. Tubes *a* and *b* had frames for slit diaphragms, tubes *c* and *d* so-called 'multiplane' shutters continuously adjustable, and *e* a slit diaphragm.

If an ordinary radiographic object, represented by a plexiglass body, was introduced, the appearance of the pin-hole photographs was not obviously changed, but a scatter disturbed the recordings.

These experiments will be sufficient as a basis for the statement

that secondary radiation produced outside the tube, inside the tube hood or in the primary diaphragm is of practically *no* importance as compared with extrafocal radiation coming from the tube itself. By the choice of suitable materials for the metal parts situated in the path of the rays, such secondary radiation may also largely be eliminated whenever necessary. Reference may be made to the discussion on combinations of materials suitable for reduction of scatter presented in the chapter on backscatter.

In the series of roentgenograms, which were all made along the axis of the central ray, eccentric and incorrect positioning of the focus relative to the tube window are visible in some cases. These inadvertencies are compensated for by a corresponding misadjustment of the primary diaphragm and are of no great consequence in the majority of exposures. There may, however, be a risk of producing one-sided vignetting, when producing large picture sizes, and such a tube is not satisfactory. In addition, this phenomenon may be an indication that the tube is not securely fixed in the hood and that the position of the focus may thus become changed with an altered position of the latter.

The influence of the glass wall and the oil in which all the examined tubes were immersed and which naturally give a certain amount of secondary radiation, seems to be of much less importance than the effect of the metal parts inside the tube. M. Williams (1936) pointed out the effect of oil in the use of therapy tubes in large tanks. The oil layer between the tube and window might be 5—6 cm which may influence materially. In diagnostic equipments, where lower kV and thinner oil layers are used the effect is much more insignificant.

The principal source of radiation outside the proper focus, which may influence the radiographic image, seems therefore to be the *true off-focus radiation* produced by secondary electrons inside the tube and, to a special extent, by the anode disc. The latter will function as a specific linear source of radiation, its effect upon the radiographic result being related to the size of the disc and to the opening in the tube. There is a characteristic distribution of the radiation in various directions through the primary diaphragm. In Fig. 79, the band-shaped distribution of radiation is easily recognized. The narrower the diaphragm opening, the more distinct is the typical spread of the radiation in the limited directions demonstrated. As a matter of fact, we have in this radiograph a kind of pin-hole camera picture of the same type as those in Fig. 83 *a—e*, only with the difference that the primary diaphragm has functioned as an enlarged pin-hole.

It may be expected that the linear source of radiation will give a representation of radiographic detail of an unusual nature, superimposed upon the true focal picture. There must be a kind of astigmatic distor-

Fig. 84. A reduction of emission appears within a band-shaped area of the focal disc. *F* is the focus and the area is indicated by the arrow. (Compare Fig. 81 *c*.)

tion, and, for instance, linear details will be affected in a way varying with their orientation to the axis of the disc. The effect is most marked when these details or contours form a right angle to the streak-shaped source of undesired radiation. For larger objects, the border zones — contours — will be influenced; for smaller and narrower ones, *e. g.* contrast-filled vessels the whole shadow will be affected by an additional amount of undesired radiation. This fact must be an important disadvantage in connection with angiography.

A peculiar observation, made on the autoradiographs of the focus, was a reduction of emitted extra-focal radiation within a band-shaped region of the focal disc. This area coincided quite well with the zone of the disc which is exposed to the primary bundle of electron rays and in which the actual focus is located. The phenomenon, which is found in the majority of tubes, appears as a darker stripe at the level of the focal spot. Compare Fig. 84 in which the stripe is indicated by an arrow. Because of the heavy over-exposure the focus itself, indicated by *F*, is not sharply defined.

A possible explanation may be that the band-shaped surface corresponding to the focus has become 'frosted' through overloading, that is, it has acquired a rough irregular surface. Such a surface will not emit so well, particularly in oblique directions. A coarse surface showing alternating microscopic peaks and valleys makes the lateral propagation of radiation from deeper regions more difficult. Similar phenomena are known in radio engineering, where polished surfaces in certain parts of electron tubes are necessary for obtaining high outputs. This is a matter of electron emission, but in other respects the problems are similar. The obliqueness of the focal surface corresponds to deviations from the direction of the rays amounting to 18 or 19 degrees, and the phenomenon will no doubt be fairly marked. However, it was present also in tubes which had been in use only for a very short time. Naturally, even in new tubes, changes in the anode disc cannot be ruled out.

Another possible explanation is that the secondary electrons in some way avoid hitting that special region, maybe because of its high temperature. If this were so, the temperature of the anode as a whole should affect the off-focus radiation. It might then be expected that the extra-focal emission would be influenced by the duration of the exposure and

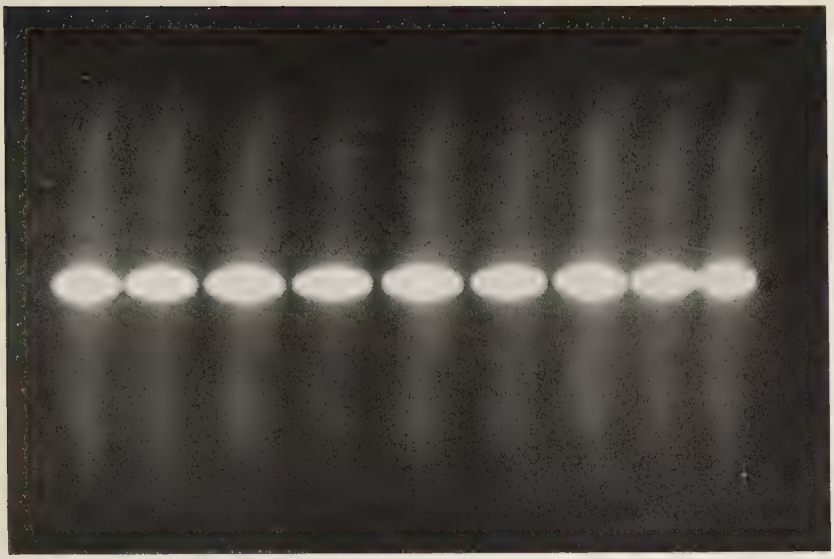


Fig. 85. Pin-hole photograph made with a rapidly moving cassette, showing a uniform distribution of off-focus radiation from the focal disc during the exposure.

that the completely cold anode, when starting the exposure, would offer conditions unlike those of the hot anode.

As the question is of interest, a brief study of it was made and I shall summarize an experiment made to evaluate the off-focus radiation and its relationship to the duration of exposure. In the pin-hole camera pictures previously shown, exposures of long duration were used. However, if a suitable pin-hole is used, a study of the time dependent upon focal and extra-focal radiation is possible with a moving film. Compare Fig. 80, to the right. Owing to the intermittent current of a four-valve apparatus, repeated exposures will be obtained corresponding to the peaks, and this may be said to constitute a kind of autocinematography. The pictures permit a study of the simultaneity of radiation emitted in various points and of their distribution and size. Rapid movement is necessary in order to obtain well-defined and separated pictures on the film. Although the pin-hole is fairly large, it will be difficult to register the complete extra-focal radiation even if the distance were the shortest possible. We must be content to register its strongest components. The cassette was given varying speeds, but only the highest of these gave good results. A speed of 1 m per second seemed to be suitable.

The observations which were made are clearly demonstrated in Fig. 85, in which an exposure was made with a mechanical timer set at 0.10 seconds, which seems to have corresponded to 9 complete current peaks

with as many repeated pictures of the disc. The strongly luminous dots in a line represent the focus. During each peak, radiation of uniform intensity and spread is emitted from the anode disc as a whole. The distribution of this radiation is remarkably homogeneous throughout all the peak exposures. The anode disc was completely cold in the beginning, and in order to obtain any result at all the kilovoltage and milliamperage were adjusted to the highest possible level. A considerable heating of the anode will have taken place during that duration of exposure. No visible difference in the intensity or distribution was obtained with this simple method; pictures, similar to Fig. 85, made after several exposures with more intense heating of the anode showed the same appearance of the peak exposures.

It is remarkable that the anode disc will be depicted so relatively sharply during the travel of the cassette. Its intensity of radiation has a very short peak parallel with the radiation maximum of the focus. A more intense exposure would possibly give a more extended picture. The blurring, which can be observed in the direction of travel probably corresponds to a movement of about 1 mm. This suggests that the moment of depiction was extremely short, of a magnitude of 1 millisecond. It is generally estimated that the disc makes about 40 rotations per second. During that short time the disc turns only about 4 % of its periphery or 1/25 of a complete revolution. Photographic registration of the disc in this manner might serve to evaluate the conditions of the disc and the tube.

Experiments were also made by means of stereoscopic pin-hole photography of the focal disc. The results gave no essential information above that obtained with the technique described in the foregoing.

No detailed study of the focus itself was made in connection with these experiments, but the problem has been discussed in many different connections in the literature. A. Frantzell's work (1951) is of special interest showing for instance the importance of the streaky inhomogeneity of emission within the focal surface for the radiographic depiction of small objects. This irregularity depends on the electron-optical system with electron-reflecting surfaces around the hot cathode, which give the bundle of electrons certain band-shaped maxima, usually three, four or five parallel bands. In the radiographic representation of a small detail, a corresponding irregularity may appear, and in fact the same rules as apply to pin-hole camera photography of the focus are applicable here. The shape, size and homogeneity of the focus will thus influence the radiographic result.

In all probability, a change in the focal disc of the type usually occurring with a frosted, coarse surface, will also be capable of changing the distribution and size of the focal emission and affect the distinct limitation of the focus.

Ordinary primary diaphragms and the off-focus radiation

To investigate how much the extra-focal radiation is eliminated with a primary diaphragm of the average type used in daily routine work, pin-hole tests similar to those described were made, likewise at ordinary tube distances. The primary diaphragm, which was situated at a distance of about 90 mm from the surface of the tube window, was adjusted to a picture size of 13 × 18 cm at the ordinary focal distance (80 cm). To produce clearly visible edges of the diaphragm, the pin-hole camera was

Fig. 86. Pin-hole photograph of a tube with diaphragming equipment of ordinary type adjusted to a picture size of 13 × 18 cm at 80 cm distance. The white points mark the corners of the aperture.

located eccentrically to one side of the central ray near to one edge of the irradiated field. One of the pin-hole photographs is shown in Fig. 86. The corners of the diaphragm aperture are indicated by small white points. It will be seen that in spite of the considerable diaphragming — such small sizes are only rarely used, for instance, in angiography — there was no considerable screening off of the off-focus radiation. A large part of the rotating disc is visible. In fact the diaphragm was oriented in the

most favourable direction, with the smallest transverse dimension directed as the radiating focal plate. If the size of the diaphragm opening had been turned 90°, the shading off of the undesired radiation would have been still smaller. No details outside the tube window were depicted in this pin-hole test.

Certain conclusions may be drawn from these observations. In spite of a small primary diaphragm, ordinarily situated, the region surrounding the focus was not screened very much. This means that a shorter tube—object distance with the consequent need of a larger diaphragm for the same object would be unfavourable. A shorter distance means a less favourable result even with the same small diaphragm, as a greater part of the interior of the tube becomes active as a source of radiation. This applies to most of the diaphragms used nowadays. The effect of a diaphragm upon the off-focus radiation will not be noticeable until its dimension is definitely below that of the tube window.

The close-to-focus principle

The correct principle in screening off unessential parts of the tube interior is to move the diaphragm a good deal *closer* to the focus and to make it *smaller*. With the same focal radiation cone quite different results are obtained, depending on the position of the diaphragm. Compare Fig. 87 which illustrates different possibilities of variation with their respective results. The absolute dimension of the diaphragm seems to be of a vital importance. Not until the off-focal region as seen from the film is screened off considerably is there any satisfying result as regards the undesired radiation. Cases 1 and 2, corresponding to two ordinary diaphragms situated far away from focus, are not satisfactory, but case 3 with the *close-to-focus* principle produces superior screening of the extra-focal radiation. The thick circles in the lower part of the picture show the radiographically active part of the interior of the tube, which in case 3 is limited to approximately the focus alone. A maximum effect is thus obtained if the diaphragm is located extremely close to the focus, so that the opening can be very small.

It is not possible to reduce the distance between the focus and the glass wall. As a rule, this distance is as short as is practically possible. During exposure, the primary electron impingement of the focal disc produces a number of secondary electrons which to a certain extent also interact with the glass; this latter is especially exposed near the edge of the anode disc, particularly in the region along the extension of the primary current of electrons beyond the disc. An interaction with heavy charges exists in the tube wall, and the glass is subjected to extreme stresses. Its

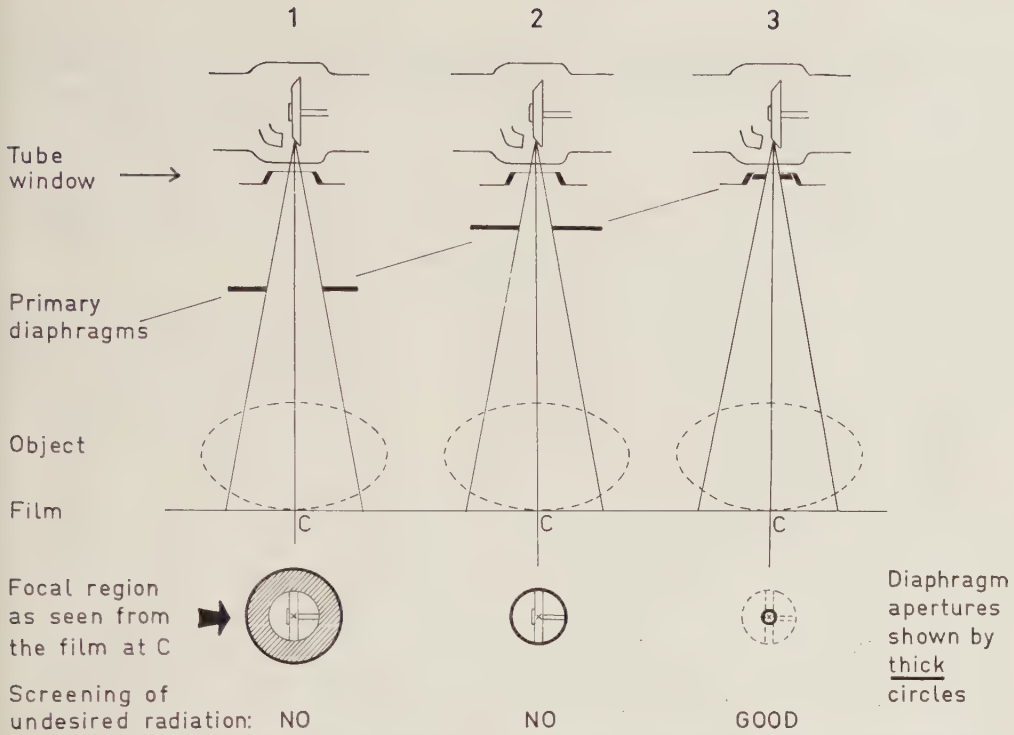


Fig. 87. The effect of varying location of the primary diaphragm upon the screening of off-focus radiation. Cases 1 and 2, corresponding to ordinary diaphragms, give no good results, but the close-to-focus principle used in case 3 gives a considerable screening of the undesired radiation. The radiographically active part of the tube in the respective case is shown within the thick circles.

strength in these regions is of vital importance for the life of the tube. The distance between the focus and the tube window is ordinarily of the size of 20 mm.

In tubes with a fixed anode, it is possible to apply a kind of primary diaphragm inside the tube. The anode in this case is surrounded by a metal sleeve or hood with a small beryllium window, corresponding to the highest part of the radiation beam cone. This arrangement is common in therapy tubes, and has also been used for diagnostic purposes during the period when fixed anodes were used. The size of the sleeve was adapted to the voltage, and for high-voltage therapy tubes the sleeve was sometimes up to 1 dm in length. The sleeve intercepts the flow of secondary electrons which is produced by the bombardment of the focus and prevents it from reaching undesirable regions of the anode or the glass. From the point of view of efficient reduction of extra-focal radiation, this is a very satisfactory arrangement. If only tubes with a fixed

anode were sufficient for diagnostic purposes this would be perfect. But the problem is a different one with rotating anodes, which are practically indispensable nowadays; a similar construction for rotating anodes is not possible. However, a type of tube as that designed by Bouwers (1930) with a rotating copper cylinder supporting the anode is said to possess better features. Since the major part of the anode is made of copper, less secondary radiation will be produced. This construction, however, seems to be but sparingly used at present.

A tube designed by E. Pohl (1934) was characterized by the arrangement of a conical anode inside a metal cylinder with the cathode. The radiation escaped from a small hole in the bottom of the cylinder and, in fact, a certain reduction of the off-focus radiation was obtained. This construction, however, was not suited for heavy duty and seems not to have been widely used.

The best answer to the problem seems to be to place the diaphragm as close to the glass as possible in modern types of tubes with rotating anodes. It has occasionally been suggested that the introduction of metal parts as close to the focus as the surface of the glass would cause a disturbance of the electric field around the focus, and might even cause a flash-over. Against this may be said that the tube housing in most cases is equipped with a conical metal hood which surrounds the opening towards the tube. Metal in this region will not exercise any influence, unless situated closer to the tube than the annular part. Furthermore, it is not absolutely necessary to use metal. It might be possible to employ other radiopaque substances and non-conductive materials which are electrically inert, *e. g.* plastic materials containing a high-absorbent filler, such as lead salts or barium sulphate. Lead glass might also be used. These possibilities are mentioned because there may be types of tubes in which the disadvantages mentioned may occur at high voltages.

It seems that the efforts to improve the primary diaphragms have mostly had in view the arrangement of more diaphragm planes, without paying much attention to the position of the innermost plane; this is of decisive importance, a fact which was emphasized as early as 1933 by K. Lindblom. Furthermore, there is no doubt a certain conservatism with respect to diaphragms. Admittedly the construction of tube hoods has in many cases rendered rational progress more difficult.

A comparison has been made between a number of primary diaphragms in daily use, both of the single and multiple plane type, as regards the position of the lead plate or lead shutters, and the results are shown graphically in Fig. 88. The distances from the tube window are represented by small horizontal lines placed according to the scale below the thick line indicating the level of the tube window. The series *a* to *m* are ordinary slit diaphragms applied to different tubes and tube

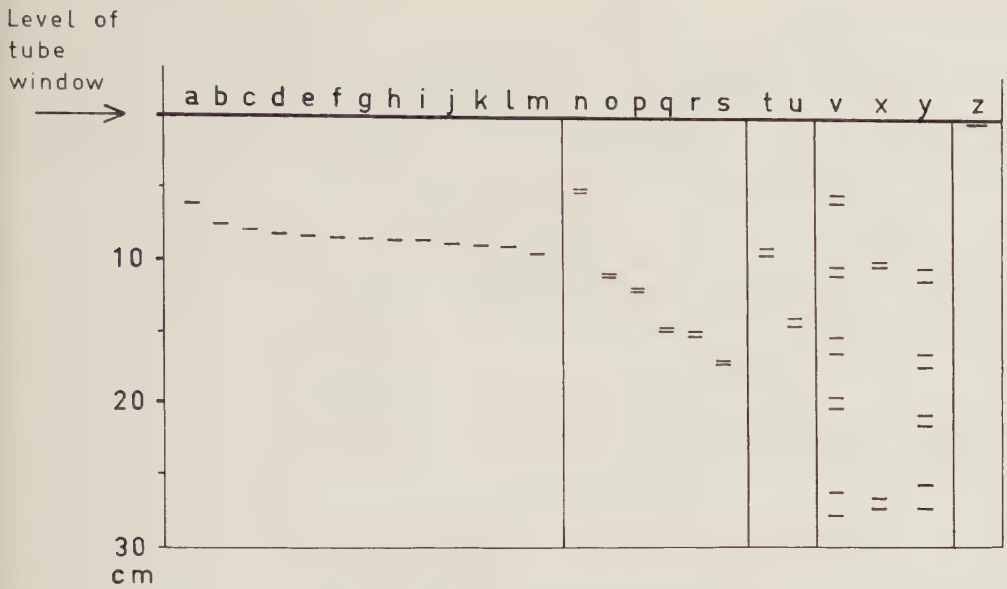


Fig. 88. Location of diaphragm apertures of different equipments in relation to the tube window. The small horizontal lines indicate, according to the scale, the levels of the diaphragms below the fat line representing the tube window. The double lines of some of the series indicate that the equipments have shutter diaphragms with the elements working in pairs close to each other. Some multiple plane shutters are included (*v* to *y*). *z* represents the close-to-focus principle.

hoods, while *n* to *s* are continuously variable single plane shutters. The diaphragming equipments *t* and *u* are similar to the latter but have optical centering devices and *v* to *y* are so called multiple plane shutters of somewhat different construction. As a comparison *z* represents the close-to-focus principle, which might eventually, if desired, be completed with a second diaphragm plane more remote from the focus.

As will be seen, no construction, aimed at bringing the single or innermost diaphragm sufficiently close to the focus, exists, and none of the diaphragming equipments studied may be said to be satisfactory as regards the off-focus radiation. Although the shape of the tube hoods to some degree has complicated an efficient solution to the problem, there has hardly been anything to prevent sound development along the lines of the close-to-focus principle.

With a diaphragm placed close to the focus and functioning *alone*, a remarkably broad penumbral region is obtained. At a distance from the focus corresponding to approximately 1/30 of the focus-film distance, a width is obtained which corresponds to 30 times the diameter of the focus. Such an unsharp limitation of the picture field is not attractive since it increases the amount of secondary radiation produced in the

object to an unnecessary extent. The effect is especially disturbing in connection with small apertures. A combination with a diaphragm placed closer to the object might therefore be made; this cuts off sharply the unnecessary penumbral part of the beam and also checks the off-focus radiation still more. It is also possible to use a kind of diaphragm, placed on the skin of the patient, in the form of a lead rubber shield with a window-like opening of suitable size.

With reference to narrow diaphragm apertures located near the focus, certain interesting phenomena may be mentioned; when the opening of the diaphragm is small, we are not far from a modified pin-hole principle. As has been stated previously, this phenomenon is observed even with fairly large apertures as seen for example in Fig. 79 on page 149. The smaller the aperture used, the more marked is the pin-hole phenomenon. A. Vallebona, in 1931, described how he employed a very small window in place of the primary diaphragm. With the tubes used at that time, the focus necessarily was comparatively large. The narrow opening transmits radiation from the whole of the focus, and the result is a fairly homogeneous cone of rays, the apex of which lies in the opening. There is an almost complete exclusion of extra-focal radiation from this beam, with an extremely small dimension of the 'pseudo-focus' from which the radiation emanates. Vallebona planned to use this construction for a direct enlarging technique with an increased object—film distance, a technique which was taken up some 20 years later, although with somewhat different equipment. When a window of the type described is employed, a large part of the primary radiation must be excluded, and the principle becomes very inefficient. It is, however, a method of obtaining a well-defined starting point for the radiation.

It may be mentioned in passing that a similar pin-hole principle has been used to obtain an extremely small starting point for radiation from radioactive substances. Cobalt 60, for instance, may be encased in a lead cone with a small hole at the tip, and used as a direct radiographic focus, particularly in roentgen microscopes. These problems, which are of very considerable interest, have occupied certain American research workers, among whom A. Margulies may be mentioned.

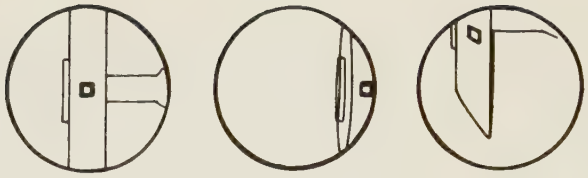
A pin-hole principle has also been used by R. J. Moon of Chicago (1950) for electronic picture amplification through a scanning system of the television type. He uses electronic radiation playing over a large focus which emits roentgen rays only from one small point at a time. Through a pin-hole, this radiation is given direction which changes constantly, and it will therefore play over the object as a very narrow pencil of rays. Behind the radiographic object is a screen receiving the impulses, the intensity of which varies with the absorption of the object. After amplification and synchronous scanning in a picture tube, an image with great wealth of detail is produced. With this special procedure, there will be no reduction of the off-focus radiation.

Experiments on the practical size of off-focus radiation

It is of value to study the relative importance of the off-focus radiation at various tube voltages. At low tube voltages one must count with a relatively soft radiation from the region around the focus with a low capacity of penetration, but at higher voltages this radiation will be harder, with a higher capacity of penetrating the body of the patient. Although the primary focal radiation will also change its character a change in the relative effect of the off-focus radiation might be possible, when using objects giving a marked filtering. According to THORAEUS, the radiation in question retains the same proportion quantitatively, independently of the voltage at least with light filtering. A series of tests was made to study the dependence of voltage during conditions similar to those in ordinary radiographic work.

The special primary diaphragm, as used in the present experiments, was a lead diaphragm with a very small aperture, which was placed directly on the glass of the tube window. Fig. 89 shows the equipment in approximately natural size. The opening was about 5 mm in diameter, and the picture size of 13 × 18 cm was covered at a distance of 80 cm by the beam passing through the diaphragm. With this equipment it was estimated that a very great deal of the undesired radiation was eliminated. A comparison was now made between a film exposed with this small close-to-focus diaphragm, and in the same manner with an ordinary diaphragm, both giving the same width of the cone of rays. A phantom made of plexiglass (Lucite), 10 cm in thickness was used. The data of exposure were identical in both cases. The experimental arrangements correspond to the alternatives 2 and 3, respectively, in Fig. 87,

Fig. 89. A diaphragm according to the close-to-focus principle used in the photographical experiments. Approximately natural size.



a *b* *c*

Fig. 90. Explanation of the variation in the amount of off-focus radiation in different parts of the radiograph. The focal plate will be more or less screened off; in *a* there is a maximum of off-focus radiation, in *b* and *c* smaller amounts. The focus is indicated by a small square.

but there was also an additional lead sheet with an opening placed directly on the phantom giving a more sharply defined limitation of the beam.

The difference in blackening of the photographic material — an ordinary screen-film combination — could be transposed into relative intensities of radiation by means of density curves worked out simultaneously for different voltages. The processing of the films was made in a developer with constant agitation and under thermostatically controlled temperature conditions.

The values of intensity corresponding to the loss of off-focus radiation with the use of the special diaphragm varied to a marked extent with different readings, all of which were made on corresponding points of the two sets of films. This may be explained by the fact that the off-focus radiation affects the image to a varying extent in different parts. One must expect that in certain parts of the beam of rays, for example in a peripheral part, the amount of the undesired radiation might be smaller. The line-shaped source of off-focus rays will be more or less shaded off even by an ordinary round aperture, when the most peripheral rays are concerned. This fact is demonstrated in Fig. 90, which shows the shading of the focal region by a round aperture for central and peripheral parts of the beam. The focal plate will be involved to a larger or smaller extent. In *a* there is a maximum of off-focus radiation. It corresponds to the centre of the picture. In *b* and *c* there are much smaller amounts.

The values of the quantity of off-focus radiation which was eliminated in the experiments varied within the region 4 to 11 % of the total radiation without the special diaphragm. It was seen that there was no evident tendency of variation in the relative size of the off-focus radiation for different voltages within the range 50 up to 110 kV, which was the maximum capacity for the three-phace apparatus used. Even though only a limited range of voltages has been tested, and there is an uncertainty because

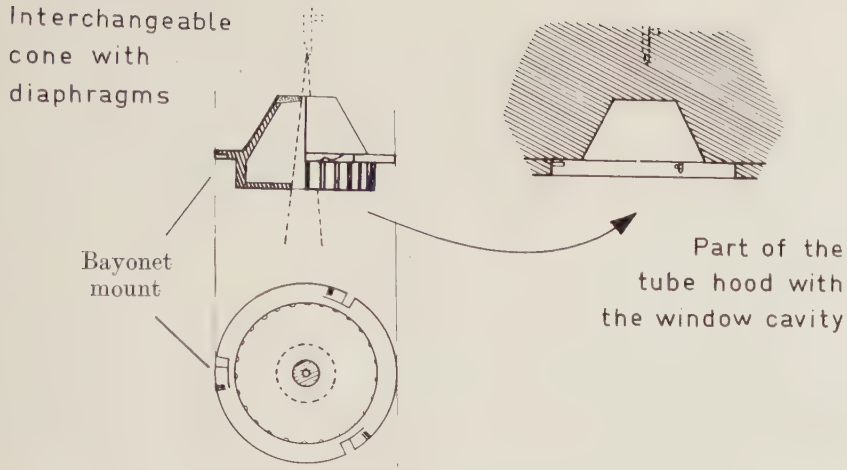


Fig. 91. A cone arrangement with centered diaphragm apertures to be fitted into the tube window cavity. The cone is easily interchangeable by means of a kind of bayonet mount.

the position of the readings influences the values obtained, and though the secondary radiation from the object may interfere, we may have reason to suppose that the observation made by THORAEUS will be valid also for a filtering corresponding to the sizes of ordinary radiographic objects.

The practical effect of the reduction of the undesired radiation is an increased clearness of the picture, especially regarding the finer details. The inaccuracy of the technique of reproduction and block making, however, makes it difficult to judge the result from reproduced pictures. Therefore I refer instead to the results of the measurements.

Practical aspects

By placing the aperture of the primary diaphragm as close to the focus as possible, preferably close to the glass, instead of its ordinary present position about 1 dm nearer to the object, an improvement in the possibilities of depiction will be obtained. It will then be found that the exposure required must be somewhat increased — the disturbing radiation has been reduced.

The close-to-focus diaphragm may preferably be supplemented by another one to obtain a better limitation of the image. The suitable way would be to use a cone arrangement with both diaphragms, one of them at a level corresponding to the ordinary diaphragms. This cone should

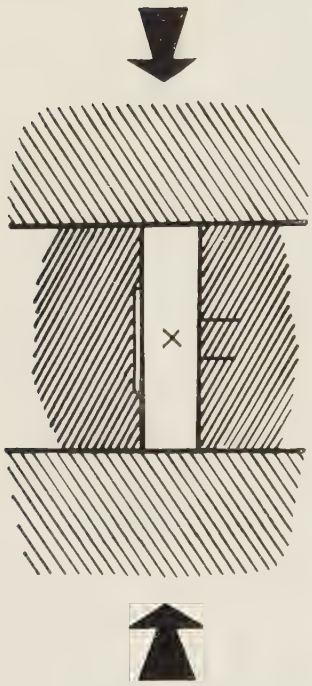


Fig. 92. A single pair of shutter elements moving against each other along the plane of the focal disc (the focus is indicated by a cross) gives a relatively effective screening of off-focus radiation. The band-shaped appearance of the source of undesired radiation makes other shutters unnecessary, and the problem of constructing a variable close-to-focus diaphragm will thus be simplified.

preferably be interchangeable by means of a bayonet mount. If this were done, it would be no more difficult to alternate between different apertures than it is at present to change slit diaphragms. Exact fitting of the openings would be necessary, and the reliability would depend on whether these always got into their right positions.

A firm bayonet mount, as used in modern cameras with interchangeable lenses, would make this possible. Older tubes could easily be equipped with these diaphragms as a supplement. A type of bayonet mounted cone is demonstrated in the layout in Fig. 91. The interchangeable equipment has a bayonet arrangement fitting on small pins of the corresponding part of the tube hood. It can be fixed into position with a slight twist. A kind of short screw-thread may also be used.

A possible alternative to the use of two diaphragms in a cone as described above, is to place the one furthest away from focus on the surface of the patient, for example in the form of a lead rubber sheet with a suitable opening cut out. Possibilities of a proper centering of the beam are of course of a great importance.

It would of course also be desirable to have facilities for varying the aperture continuously, but with the present types of tube hoods the problems do not seem easy to solve. To introduce a variable shutter mechanism in the window cavity is difficult. If the necessary space for such a mechanism was reserved in the construction of the hoods, the problem would be an easy one. In the use of variable diaphragms with two planes the near-to-focus aperture, however, may be simplified. Because of the characteristic bandshaped appearance of the source of undesired radiation, the anode disc, a relatively effective screening of this radiation will be obtained with only *two* single shutter elements moving against each other along the plane of the disc. Fig. 92 shows the simple principle. The movable parts may then be synchronized with the corresponding pair of shutters of the other plane more far away from focus. This possibility makes the use and construction of variable diaphragms much easier.

Conclusions

Compared with other sources of secondary radiation connected to the tube the secondary emission from the focal disc is of a clear predominance. Radiation from the primary diaphragming equipments, cones or shutters, have no practical radiographic importance. Thus the arranging of series of lead shutters at different levels seems to be without value from this point of view. The most important thing is the placing of a very small diaphragm very close to the focus, which reduces the real off-focus radiation. No primary diaphragm equipment available at present seems to be constructed for an effective reduction of this picture-disturbing radiation.

Investigations with a close-to-focus diaphragm show that there is a marked filtering of the off-focus radiation. The effectivity of such a diaphragm is correlated inversely to the size of its aperture. The nearer the location of the aperture to the apex of the radiation cone the better the result.

A close-to-focus diaphragm should preferably be combined with a diaphragm situated nearer to the object — *e. g.* at the ordinary level of diaphragms — in order to give a more sharply defined beam and a still more effective screening.

THE BACKSCATTER PHENOMENON

Some introductory tests

A series of experiments were made for the purpose of ascertaining the effect of secondary radiation produced in the immediate neighbourhood of the photographic layer, in the first place, backscatter. In order to be able to assess the secondary radiation selectively, the film was covered with small lead discs placed so that a small part of the film was completely protected. Fig. 93 illustrates the principle of the experimental arrangement. The white arrow in the figure indicates the place where the film is exposed to radiation from behind. Round discs placed eccentrically, or a strip and a round disc, were combined. The same principle was used both for studies in connection with non-screen technique and with cassettes.

The value of placing, for instance, a sheet of lead behind the film to limit the effects of secondary radiation from behind has been pointed out by several authors, among others by H. Laurell (1932), D. v. Dijk (1951) and K. C. Clark (1953). The latter author recommends a lead sheet, 0.5 mm in thickness, for this purpose in high-voltage technique.

That an improvement in the quality of an image will be obtained if backscatter can be eliminated is generally known from routine work. It is of interest, however, to study more closely the topographic conditions and the intensity of the backscatter. The present tests show clearly that objects situated closest to the photographic material may be considered as the main sources of secondary radiation. Such a medium may be the plexiglass (Perspex, Lucite) plate on which the film rests, for instance in non-screen radiography of skeletal objects. The distance between this plate as the source of secondary radiation and the film is only a few millimetres. The objects situated further away are of minor importance because of the longer distance. The nature of the material from which secondary radiation emanates is of very great importance. The plexiglass plate is placed high on the scale together with many other light substances, while metal parts in grid mechanisms are of less importance.

Fig. 94 shows some of the experimental films made with non-screen film. The film was covered with a round lead sheet, a similar sheet being interposed between the film and the support. The two sheets were placed eccentrically in relation to one another, and the half-moon visible on the

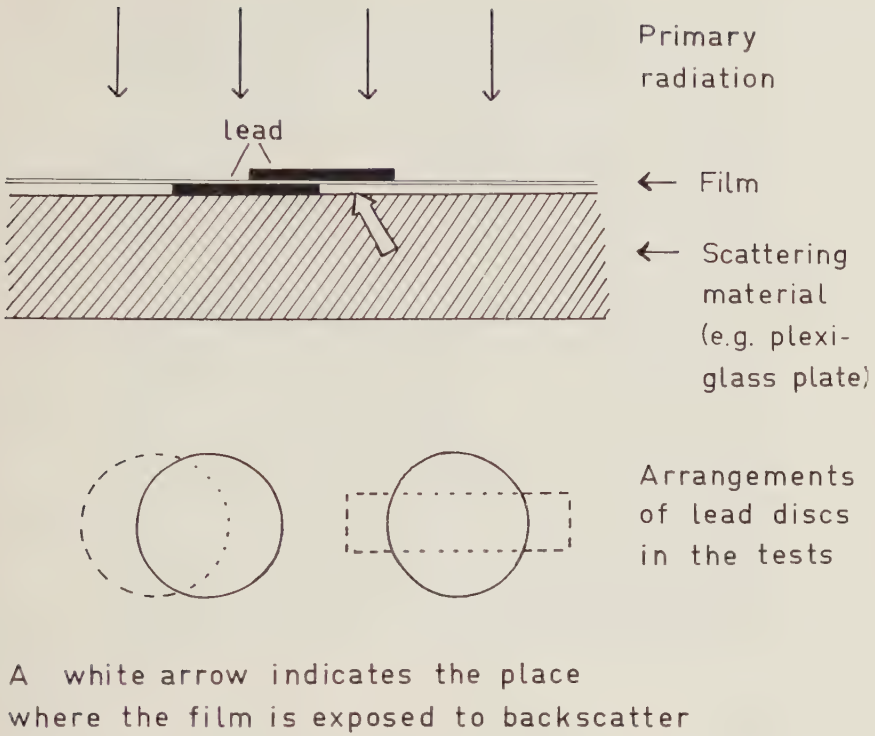


Fig. 93. Principle of the experimental arrangement used in the study of backscatter.

rounded area was caused by backward scatter. All the experiments were carried out on an ordinary skull table. In Fig. 94 *a* the film was placed directly on the plexiglass plate, which was 10 mm in thickness, the usual grid mechanism lying below. In Fig. 94 *b* the conditions were the same, though with the grid and its mechanism removed. In Fig. 94 *c* the plexiglass layer was increased by adding a further 40 mm of material, which, as will be seen, increased the effect, whereas in the other two tests no great difference was noticeable. Fig. 94 *d* shows the effect when the film with the lead discs was placed below the plexiglass plate and the grid mechanism was removed. No signs of backscatter appeared. In all of the tests the density of the surrounding area was maintained constant. The tests were carried out at different kilovoltages, of which those performed at 90 kV are illustrated here. It was found that the density obtained by backscatter is related to the thickness of the plate situated beneath the film, while other objects in the roentgen apparatus are of almost no importance. Again, if the film was lifted from the surface, a more diffuse effect of the radiation was obtained. The plate and film were separated

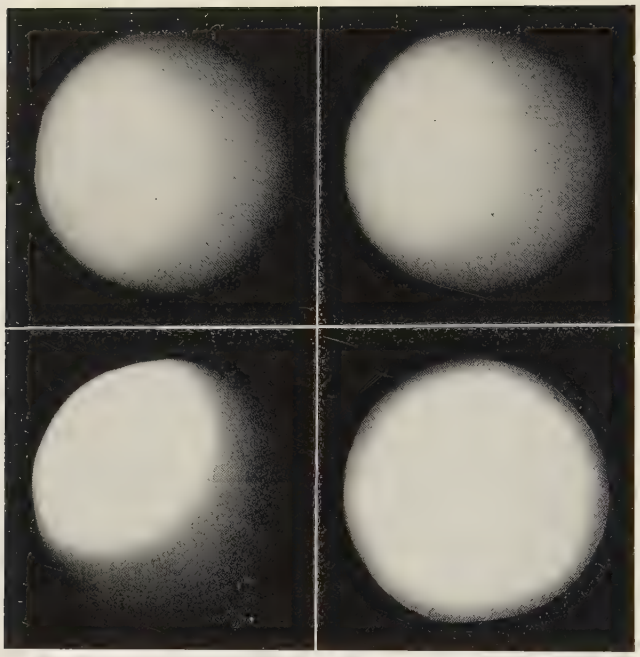


Fig. 94. Backscatter from a plexiglass plate situated close to the film. *a*: ordinary plexiglass plate (10 mm in thickness) + grid mechanism 2 cm behind. *b*: ordinary plexiglass plate with no grid mechanism behind it. *c*: plexiglass plate of increased thickness (40 mm added). *d*: film placed below plexiglass plate, grid mechanism removed. The halfmoon shaped fields of blackening inside the round surfaces are caused by backscatter radiation.

further in order to localize the source of radiation and a small shadow-producing lead pellet was placed between them. The resultant films still showed very diffuse dispersion, indicating that the plate was the predominating source of radiation. These observations refer to the skull table but may be considered to be representative also of other apparatus of similar design.

The tests described were carried out both at different voltages and with and without an object — 10 cm of plexiglass — and similar results obtained. The illumination of the film was adjusted so as to produce densities of the same order of magnitude. The densities on the parts of the film irradiated by the backscatter, measured densitometrically, show that we are concerned with an amount of radiation which, in relation to the primary radiation, constitutes 5 to 10 per cent. These figures, however, are by no means a measure of its importance. From what has been said, it is evident that the density is particularly marked on those regions of the films, slightly exposed and near to dense parts. G. Spiegler

(1950) pointed out that the thin regions of the film are most sensitive to scattered radiation. It may be expected that the effect would be of particular value in, for example, radiography of the bones, where intensely dense areas in the film border upon fairly thin ones. Observations made in routine work bear out this presumption. The backscatter radiation corresponding to the surroundings thus produces a sort of fog in the adjacent skeletal parts. The general increase in the density of the film corresponding to the above percentage is of much less significance. The importance of the backscatter phenomenon is thus greatly dependent on the character of the object.

No noteworthy relationship between backscatter and kilovoltage was noted in these tests and no apparent increase in the backscatter at higher voltages was observed. As E. H. Quimby, C. D. Lucas, A. N. Arneson and W. S. Mac Comb (1934) have demonstrated, backscatter really increases with the effective wavelength. The effect is scarcely noticeable in the limited region used in the present experiments. The latter authors have discussed the problems in connection with therapy. E. H. Quimby, L. D. Marinelli and J. H. Farrow (1938) found that there was a maximum corresponding to a fairly low filtration. With higher energy, the secondary radiation propagates more expansively in the direction of the primary beam. These problems have been graphically illustrated by H. E. Jones (1953).

Methods of reducing backscatter

The most effective way to check backward scatter is by introducing a thin metal sheet immediately behind or below the film. This will not only limit the amount of scattered radiation but also prevent it from occurring by reducing the irradiation of the scattering medium. Lead sheets have mostly been used to prevent scatter, as in the present tests. In fact, since the actual radiation is very low, a very thin layer of lead will suffice; 0.5 mm as recommended by Clark seems to be unnecessary and 0.2 to 0.3 mm is probably sufficient. For non-screen radiography, however, thicker lead sheets or lead rubber appear to have been used.

A fact to be considered is that backscatter may also emanate from the lead itself at the higher energies of the primary radiation. B. Cassen and K. Corrigan (1938) have also entertained this view, although not exactly in this connection. They discussed the backscattering from lead used as protection, for instance, on walls and suggested a way of reducing it by using a specially designed lead sheet, tooth-shaped in cross-section, forming a pattern of lamellae situated vertically close to each other. The secondary radiation emanating from the lead itself will thus pass through a kind of grid which reduces the dispersion to a considerable

degree. This grid-shaped arrangement is found to be particularly effective in directions at right angle to the lamellas, as these authors have demonstrated by measurements recorded graphically. It may be that the solution of the problems presented in the following is a simpler one. It should be pointed out that a rough surface of the lead is always preferable to a smooth one, which produces a higher secondary emission.

The secondary radiation from lead increases considerably with higher voltages, as has been shown by the authors quoted below. At voltages up to 100 kV under the test conditions described this effect has not been noticeable, but as will be shown, it appears at higher voltages. It would therefore appear to be justifiable to consider also the high kilovoltages and to choose the most effective means of methods for preventing backscatter.

An antiscattering foil

The secondary radiation from lead is reduced by covering it with a thin layer of iron from which an extremely small amount of secondary radiation emanates. References may be made to L. Lorentzon's (1954) studies on secondary radiation from different substances in association with the problem of radiation protection, in which he demonstrated the characteristics of iron in this respect. B. Lindell (1954) and R. Walstam (1954) showed the influence of secondary filters and the value of covering lead with a thin layer of iron, *e. g.* 0.05 mm in thickness. This causes a very marked reduction in the L-radiation of the lead, which, as shown by Lorentzon, contributes greatly to the secondary radiation.

Since stainless steel, which does not corrode and which may be obtained in thin sheets, has the same properties as iron in this respect, I considered it justifiable to use a lead sheet covered with this material. It provides a very effective means of preventing secondary radiation at all the kilovoltages used and is also more pleasant to handle than lead alone, and, in addition, forms a protective cover. A specially designed disc to be used as a support in, for instance, non-screen radiography of bones, has been constructed in this way. Its application will be seen in Fig. 95.

It consists of a stainless steel foil, 0.1 mm in thickness, placed on the lead sheet, which in this case is 0.5 mm thick. The two metals are held together by a method of soldering on the principle used in the manufacture of metal grids. A suitable size seems to be 30 × 30 cm. There is a cardboard plate on the backside and two small handles are provided.

A test of the effectivity of the stainless steel-covered lead plate is shown in Fig. 96, in which a comparison is made with a plate of lead alone. A film is supported partly by the steel-covered plate and partly

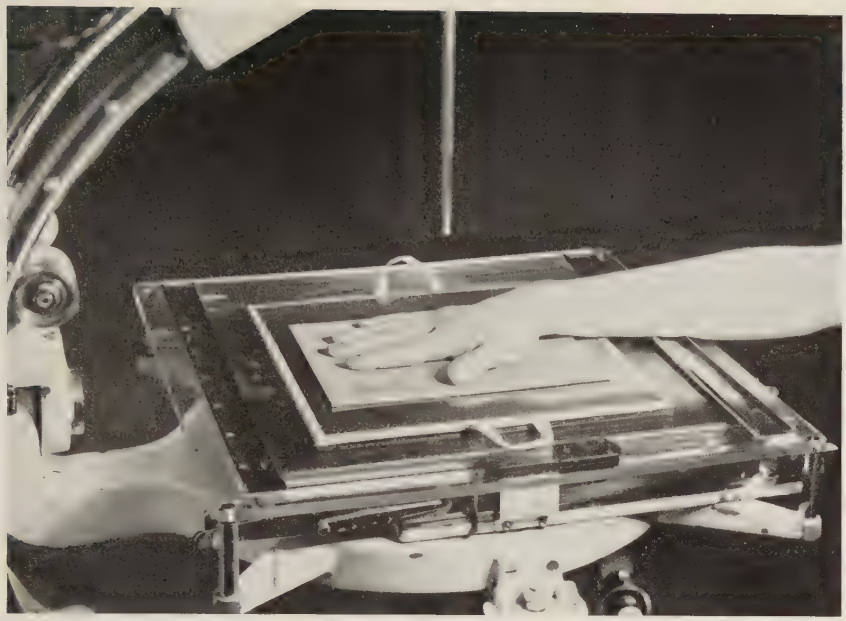
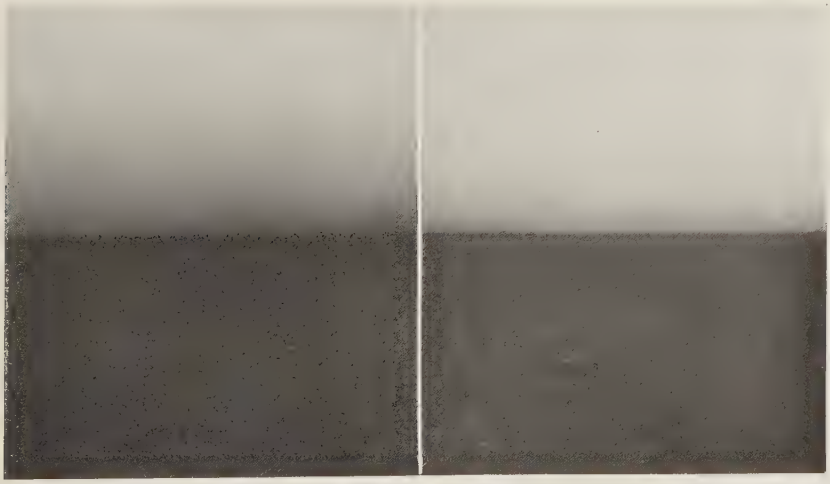


Fig. 95. A special anti-scatter metal plate for use in skeletal radiography with non-screen film. It is shown in use on a skull table outfit. The plate, which has a surface of stainless steel, has a size of 30 × 30 cm. It is clean and convenient in use, and provided with two small handles.



a *b*

Fig. 96. Demonstration of the reduction of back-scatter with the anti-scatter plate. The two films show, on an exaggerated scale, the edge of a lead sheet covering the upper parts of the films, thus protecting them from the primary beam. In *a* the film was supported by a lead plate, in *b* by the anti-scatter plate. The blackening in the upper half of film *a* near the edge is produced by back-scatter. This is much less pronounced in film *b*. 5×.

by the all-lead plate. A lead disc is placed on the film, partly protecting it during the exposure which was made at 125 kV. The backscatter from the support reaches the unexposed area of the film at the margin of the disc. The lead gives a more marked scatter, shown in *a*, compared to the special anti-scattering plate (*b*).

It should be pointed out that stainless steel may be advantageously used in other similar procedures for the purpose of limiting the amount of secondary radiation from lead. The problem may possibly arise in connection with certain protection arrangements. For special purposes, iron may possibly be used in powder form with varnish as a binder.

Most manufacturers of film deliver the non-screen material in special single packages ready for use. These have cardboard backing to make the envelope stiffer and protect it from breaking and bending. It is probable that this backing may produce slight backscatter. In this respect, envelopes without cardboard are preferable.

The backscatter in cassettes

The problem of backscatter in the use of cassettes has also been studied. It is well known that most cassettes are fitted with a back panel covered with a thin lead sheet to absorb secondary radiation. From certain tests of the makes available, the thickness of the lead sheets amounts to 0.1 to 0.2 mm. A remarkable fact is that there are cassettes manufactured without this lead foil, so that they may be used with either side facing the tube. This possibility seems to leave out the fact that the front and back screens are generally different and should be used in a definite position with the thinner screen as the front screen. An effective lead sheet is no doubt indispensable. According to recent investigations by H. Schober (1954), not yet published, 0.2 mm of lead should be fully sufficient for voltages up to 150 kV.

The lead sheet is generally interposed between the back panel and the pressure pad, usually of felt; this latter, being elastic, will exert an even pressure over the entire screens so as to ensure satisfactory contact between the film and the screen and the optimum sharpness of image. Since I found that objects in the immediate neighbourhood of the film, light substances in particular, could be such important factors with regard to secondary radiation, I considered it necessary to make a close study of the problem of backscatter with special reference to the material used for the pressure pad of the cassette. The pressure pad may be suspected of producing some backscatter effect.

Tests were carried out similarly to those described before, with a

a *b* *c*

Fig. 97 *a—c*. The back-scatter from the pressure material in cassettes (felt, foam rubber and foam plastic, respectively) causes the small dense areas beside the white bands inside every circle.

lead disc placed in the primary beam and a thin strip of lead interposed between the back screen and the pressure pad. Compare Fig. 93. Three different kinds of pressure material were tested: felt, foam rubber and foam plastic. Layers of equal thickness were used and all tests were carried out under exactly the same conditions. Fig. 97 *a—c* show the results of the experiments, which were made in a cassette of ordinary type. Within the round areas there is a distinctly denser area next to the non-exposed field which was covered with the lead strip. The difference in sharpness of the round area, where the back-scatter is present and where it is not present, may also be noted. Similar results were obtained with the three materials, a slightly higher density being observed for the foam rubber (Fig. 97 *b*). Different makes of this product, however, have varying properties as regards, for instance, specific gravity and porosity, so that the result of a comparison is not of general applicability.

The order of magnitude of the added amount of secondary radiation may be estimated densitometrically at about 5 % of the primary radiation. In accordance with what has been said in the foregoing, its effect should be most marked in the case of objects with great differences in illumination, in which sparsely illuminated regions may be diffusely fogged in areas bordering on strongly illuminated regions.

The backscatter protection of cassettes should therefore be supplemented, so that the effect of the pressure material is reduced. For this purpose, a thin metal foil should be interposed between the pressure pad and the film, that is against the back screen. For reasons already stated, iron may be considered suitable. A layer of some 0.1 mm of iron or stainless steel, may be advantageously used. The backscatter protection in a cassette should be arranged as shown in Fig. 98. The lead foil is situated close to the back panel, and on the other side of the pressure pad and

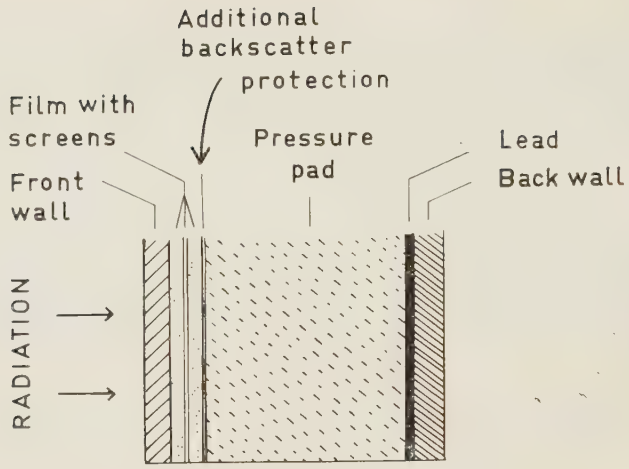


Fig. 98. A magnified section through a cassette provided with an additional back-scatter protection in the form of a thin metal sheet (*e. g.* iron) between the back-scatter and the pressure material.

against the back screen lies the iron foil. Instead of a metal sheet it seems possible to use a coating of iron powder with varnish as a binder. Iron in oxide form might also possibly be used.

A related secondary radiation effect

In view of the large amounts of secondary radiation which may arise from plexiglass when this is situated in close contact with the film, attention should also be paid to those cases in which a plexiglass plate is located on the opposite side, that is, on the side of the film facing the tube. This does not seldom occur, but in most instances a secondary diaphragm intervenes, thus reducing the undesirable radiation. Some types of film changers, however, where uniform pressure is required on exposure, have such plates of large dimensions with the grid *in front* of them. It should be noted that the amount of secondary radiation from the plate would be comparatively large on the film side due to what has been said earlier concerning its dispersion at high kilovoltages.

Some experiments were carried out in order to study the densities produced by secondary radiation on a film with screens behind a plexiglass plate, when the grid was placed on either side of the plate. The experimental conditions will represent the possibilities of arranging the grid shown in Fig. 99 *a* and *b*, where grid and plexiglass plate change place. A cross-grid and a plexiglass plate, 13 mm in thickness were used. A small lead strip was used as test object together with a plexiglass body. A round piece of lead was placed directly on the front screen.

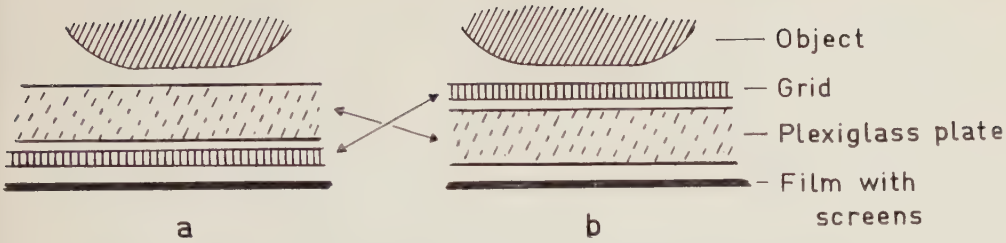


Fig. 99. Possible arrangements of the grid in relation to the plexiglass plate.

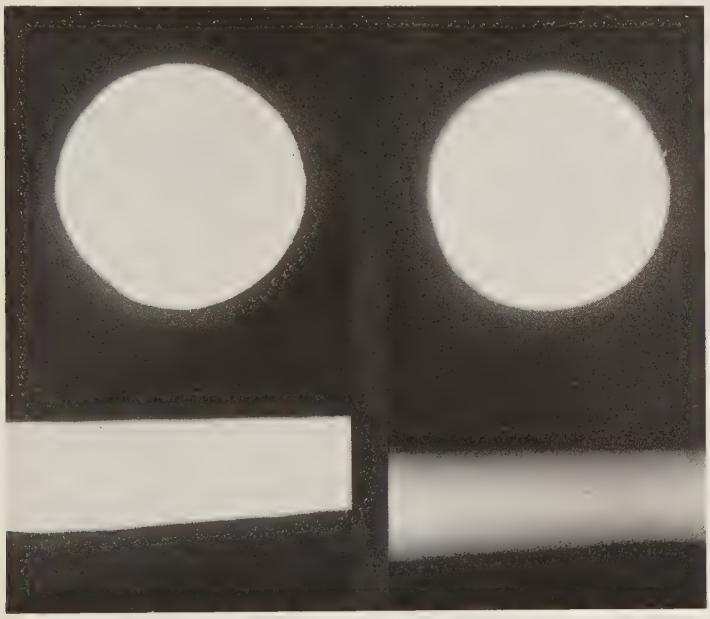


Fig. 100. Scatter from a plexiglass plate placed in front of the film, when the grid was located on either side of the plate. The horizontal bands correspond to a lead strip, used as test object. The rounded area is a piece of lead close to the film. In *a* the grid was located behind the plate, in *b* in front of it. In the latter case a considerable blackening appears behind the lead strip. Note also the difference in sharpness of the rounded area, because of scatter.

In Fig. 100 *a* and *b*, which shows test films produced at 100 kV, the horizontal band corresponds to the lead strip, the rounded area above it represents the lead piece just mentioned. In Fig. 100 *a* the grid was located behind the plate, in Fig. 100 *b* in front of it. In the latter case there is a considerable density produced behind the lead strip by the additional secondary radiation. Densitometrically this radiation amounts to some 5 % of that giving the surrounding density. The arrange-

ment of the grid behind all objects producing scatter, as in the former case, seems thus to be preferable.

Since in some respects the amount of radiation is related to the thickness of the plexiglass plate, a very thin plate should be chosen, or it may be considered that aluminium, which, by reason of its mechanical strength may be employed in thin sheets, is to be preferred. As is known, experiences with aluminium as used in the construction of cassettes are very favourable. The designer of film changers should make greater allowances for the factors discussed, since in some cases they may be of considerable significance.

A PHANTOM FOR THE STUDY OF THE RADIOGRAPHIC RECORDING OF VESSELS CONTAINING CONTRAST MEDIA

The need of a special test object. Some references

The radiography of small vessels involves problems that are quite specific and the technical prerequisites have to be thoroughly investigated with a view to the use of higher voltages. Many factors influence the radiographic result, among them the characteristic properties of the contrast media. The best way to carry out trials of this nature is to make phantom investigations with a test object in order to study and evaluate the recording of small volumes of the substances concerned — angiographic contrast media.

It should also be noted that in recording small objects special conditions will arise because of the special character of the focus. These have been discussed by A. Frantzell (1950), who pointed out that a very small object in the picture corresponds to a penumbral figure in which structures from the focus may be recognized. This is a parallel to the picture of the pin-hole camera. In order to be able to assess the possibilities of recording special objects — *e. g.* vessels — with which we are concerned here, the tests should be carried out with objects resembling vessels. It is probably in no way correct to apply observations on, for instance, punctiform objects to the study of vessels in assessing the contrast and the resolving power.

A few words should be said about different types of phantoms used for testing the quality of the recording. Many constructions have been used for the assessment of the value of various radiographic techniques. W. W. Fray and W. T. Hill (1933) used a simple principle with two fine wires placed with a slight divergence so that they partly fused in the picture. The point at which the objects were seen to be separated was considered to be representative of the resolving power. With poor resolving power and inferior radiographic technique it was to be expected that they would not be seen separated until at a point where they actually diverged considerably. This method, however, is considered to involve sources of error because of, for instance, the influence of suggestion in determining the point where the shadows of the two wires fused.

Phantoms made to assess, for instance, the technique of radiography of the lungs have had test objects in the form of points or figures of different dimensions, their visibility on the film being a measure of the resolving power of the technique. G. C. E. Burger and D. v. Dijk (1938) used a pertinax (bakelithe laminate) phantom with figures or letters of different height and thickness. They also used plates of different thickness in which they drilled holes of various sizes. O. Axén (1941) applied a similar method with figures made of aluminium and other metals. Both these works were mostly concerned with fluoroscopy. A. Nelson, (1949) in investigations comprising fluoroscopy, used plexiglass plates into which he drilled holes of various depth producing varying contrast. The holes were arranged in a systematical order, which is considered to be a disadvantage, since the observer under the influence of suggestion may see points which are not actually present. These views, which also apply to phantoms made by H. Distel (1949) have been presented by Schober (1951) and others. The so-called Landolt's rings, used in Schober's own phantom, are characterized by the fact that, in reading, the position of a certain defect in the rounded figure has to be defined. Since its position is arbitrary, suggestion cannot play a part in this technique. Reference may be made to what has been said previously about this phantom, which was used for the determination of the definition with and without grid structure. Fig. 56 on page 116 shows a photograph of a detail of the phantom. A few of the about fifty rings are visible.

Other more simple objects have also been used to assess the resolving power with different techniques. A well-known stellate figure, used for many years for testing cameras for fluoroscopy, was discussed for instance by G. Schumann (1953). It is a round plate made of plexiglass with radially arranged strips with a triangular cross section surface, the size of which decreased towards the centre. With this arrangement it is of course possible to assess the resolving power, since it enables the observer to tell how near to the centre the grooves in the object are discernible. Like many others, this method is not entirely reliable owing again to the risk of suggestion.

A method for the production of vessel phantoms

The problem is to produce test objects representing the character of vessels filled with contrast medium suitable for phantom tests.

The active component from the point of view of contrast is ordinarily iodine. It cannot be replaced by a metal without producing significant errors because of the difference in absorption. For this reason com-

pounds containing iodine have to be used. Experiments were made to find out whether some solid iodine compound could be tried — it might possibly be easier in that way to produce small constant objects, for instance in the form of small tubes or wires.

Experiments with iodized oil mixed with paraffin of a high melting point, which could be made in the form of small suitable objects, showed a marked difference in variation of contrast with the voltage in comparison with water solutions of contrast media. It appeared necessary to use fluid contrast media in water solutions. Attempts to obtain these in a viscous or gelatinous form with the high concentrations, are doomed to failure. Crystallization is very likely to occur at each addition of foreign substances. Tests made with fine tubes of polyethene and similar plastic materials filled with contrast media were not successful, since the tubes themselves were too easily visible.

A solution of the problem which was found to be practicable, was to enclose the water-soluble contrast media in small cavities in a casting material of an organic nature. By means of metal wires of different calibres the desired dimensions of the holes could be obtained in the moulding.

The first experiments were made with paraffin, but it was found that after casting the wires could hardly be extracted without causing damage to the material. Other thermoplastic materials with a density similar to that of organic tissues were tried. The thermoplastic impression compounds used by dentists (Kerr, Paribar and Nadrag) are especially suited for models of fine details. None of them gave satisfactory results for this specific purpose. The ideal seemed to be a substance that, on becoming solid, would retract to a certain extent so that the wires did not become completely fixed in the solid mass. Attempts to coat the wires with a silicone preparation in order to prevent the material from adhering too firmly, did not seem to be of much value. After tests it was found that stearic acid of the type used in ordinary so-called stearine candles had the suitable properties. After it had hardened, inserted wires of all dimensions could be extracted, and in this way lumina resembling vessels were obtained. The stearine did not seem to adhere too firmly to the wires, which could be extracted after cooling, although in the case of the thinnest wires there was considerable friction.

The technique of producing the phantom will be briefly described. Using a wooden model of suitable dimensions, a mould was made of tin foil 0.2 mm in thickness, which was folded in such a way that the mould became liquid-proof. It had the shape of a small box. The wires, which were absolutely straight, were pulled through small holes in the sides of the box across to the opposite side, and a loop was made at one end of each wire. The melted substance, at not too high a temperature, was kept in a suitable container. A small quantity of the melted substance was poured into the mould and, by tilting distributed over the interior of the box, covering the holes in the sides, which in this way were closed. The mould was then placed in cold water up to about the level of the side-holes. The melted substance could then without risk be poured into the mould, usually up to its upper edge. After about half a minute, and when the surface had partly set, there was no longer any risk of leakage through the small holes at the end of the wires, which was a great problem in the first experiments. The mould with its contents was then taken out of the water and the surface was covered with wadding for insulation, since it was found that slow cooling was of the greatest importance to

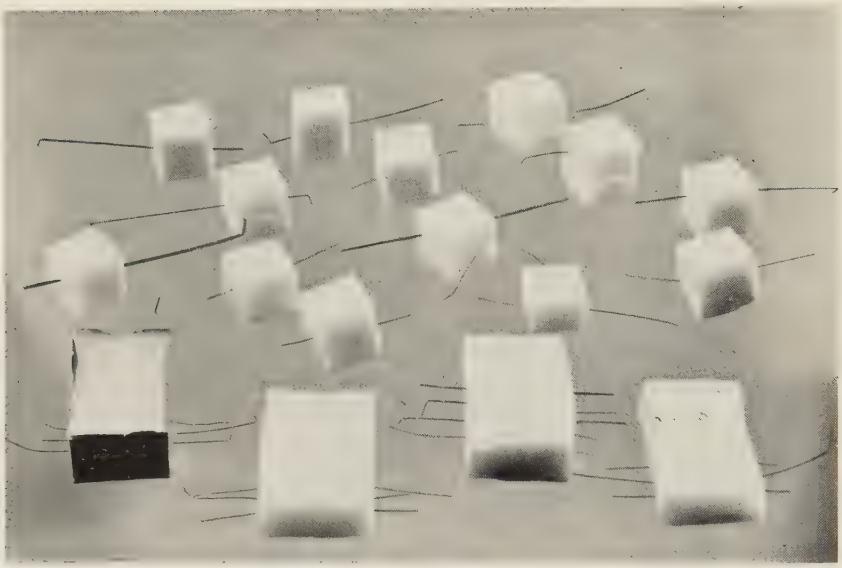


Fig. 101. The castings with metal wires used to produce vessel-like channels.

the homogeneity of the substance. Irregular and too rapid cooling produced porosities and cracks. After complete setting, which usually took about one hour, some degree of after-hardening was found to occur. For this reason it was advisable to allow the castings to stand for a few days before being used.

The completed casting has to be trimmed, since it sometimes diverges from the shape of the mould, and since the upper surface frequently bulges and is uneven. The trimming is done with a knife and a rasp. The corners may also be rounded off.

Different types of castings were made. A number of blocks in the process of construction with the wires not yet extracted are shown in Fig. 101. In the upper series in the picture are seen blocks with only one wire. In the lower series closest to the camera are blocks each with many wires. Furthest to the left is a casting still in the mould.

The process of substituting the wires by a fluid required some precision. After the wires had been carefully extracted, channels up to 15 to 25 mm in length were produced. The contrast media used were ordinary water solutions of 35 or 50 % concentrations. To facilitate the observation and the handling of the small quantities required, a few minute crystals of methylene blue were added to the solutions. The latter thus acquired a colour which made it easier to see when sufficient solution had been drawn up, and to watch whether any of it had leaked out. A few drops were quickly placed on a glass plate, the casting was placed close to the side of the plate with its openings in the solution and from the opposite side the solution was sucked up by means of a tube with a soft transparent closely fitting edge of plastic. Because of the colour of the solution it was immediately visible when it had passed through to the other side. When the channels had been filled, any superfluous solution had been dried off with blotting-paper and the sides of the box were completely dry, the holes were closed with

a cellulose glue which was laid on and allowed to dry. Different methods of closing the holes were tried, for instance by melting, but the one described here seems to be the simplest. After the holes had been closed the phantom was ready for use.

It might be expected that the enclosed amounts of solution would remain unaltered for a long time. Unfortunately this is not so. A crystallization process seems to begin after a few hours. This is accompanied by a change in volume. The closing layer cracks and the liquid leaks out. The change occurs most readily with the higher concentration. It seems to be most marked with the usual iodine preparations with two molecules, and is less marked with new compounds of the Urokon type. In control radiographs of the castings the change is very clearly seen. However, these phenomena are of no great disadvantage. With the necessary appliances at hand the blocks may be easily prepared directly before use. It is convenient to have a series of completed castings in readiness for the filling.

A few words should be said about the wire material. Different metals were tried and it was found that stainless steel and silver plated wire were the most suitable materials. Of these the latter had the suitable stiffness for most dimensions, while the stainless steel wire seemed to be the better for the smallest dimensions, where the silver plated wire was too soft. Diameters between 1.0 and 0.1 mm were used. The diameter was checked with a micrometer screw gauge.

To eliminate the influence of suggestion when using the test objects for ascertaining the degree of definition and visibility, a type of casting with a single channel was devised. By being placed in varying ways it provides great possibilities of variation in the position of the observable structure. The diameter of the channels may be varied from 0.1 mm and upwards. When the position of the contrast-filled channel can be correctly interpreted, the contrast medium in the block may be said to be clearly visible. At the reading of a test film, in which a series of blocks has been recorded, the problem is to see down to what size the lumen can be observed.

This type of block is cube-shaped. The channel of each block has a characteristic position extending from the middle of one of the lateral surfaces to an asymmetrical point on the opposite side. This special arrangement makes the variation of the radiographic appearance of the block still easier, since a new combination of possibilities will be obtained when the block is turned upside down.

In this way conditions similar to those present with SCHOBER's phantom may be produced. In this case, however, one has objects of a nature closely corresponding to the real radiographic conditions regarding form and size of the details as well as the substances concerned. The latter may also be chosen at will.

It should be pointed out that the straight-lined details produced here are probably easier to observe on the films than details that are short and curved, as is sometimes the case with vessels in the body. The character of the background is probably of greater importance in the case of the latter.

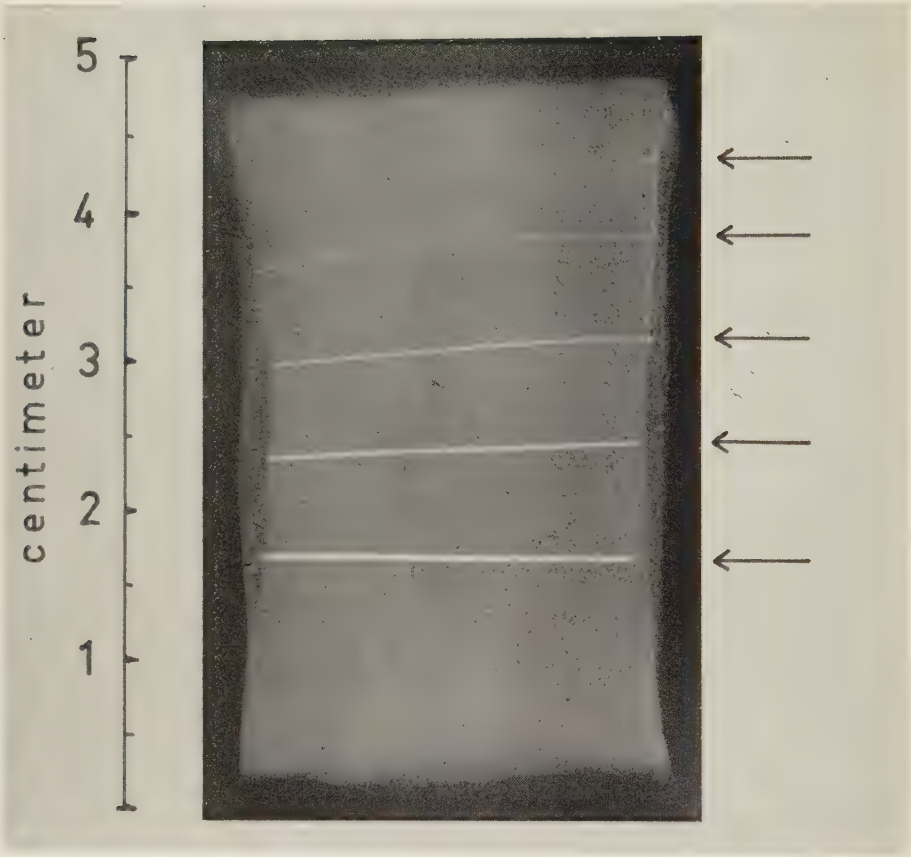


Fig. 102. A block with five channels filled with Umbradil 50 %. Diameters varying from 0.1 to 0.5 mm. Magnified radiograph made on non-screen film.

The other type of block, used in the experiments next described, consisted of a rectangular casting slightly smaller than an ordinary matchbox with a series of channels placed side by side. The block measured about 25 × 10 × 50 mm and the arrangement was intended mainly for being recorded together with the radiographic object placed in a suitable manner. A radiograph on non-screen film of such a block with a series of channels filled with contrast media is shown in Fig. 102. The diameters of the channels shown vary from 0.1 mm up to 0.5 mm. For the microdensitometric studies the channels were of somewhat larger sizes and filled with contrast media of two different concentrations.

Practical applications of the vessel-like test objects

To obtain a general orientation concerning the concentration of contrast media inside the body during angiographic examinations a series of experiments were made in connection with routine angiographies in the roentgen department. These experiments served several purposes. Besides being of a certain general interest from an angiographic point of view they also provided a guidance as to the proper choice of concentration of contrast medium in the test objects described above and in the study of the influence of voltage on the contrast as presented in a previous chapter. Densitometric studies of the recordings of vessels were made and compared with those of the vessel phantom.

A radiographic examination suited for investigations of this special character is the pelvic arteriography. By placing the comparison object containing channels of known size filled with contrast media of known concentration inside the body — introduced into the vagina — it is possible to obtain a simultaneous radiographic recording of these channels and the branches of contrast filled vessels. Vessels located anatomically in an equivalent manner to the test object might then be selected and studied in the films.

The vessel phantom which was prepared just before the examination, was firstly inserted into a thin plastic cover. It was introduced carefully into the vagina, special attention being paid to the position of the block so that the channels lay in a horizontal orientation. A plexiglass plate placed horizontally above the patient gave a compression resulting in a practically uniform thickness of the soft tissues over the whole irradiated area. The examinations were performed in the usual manner according to the method devised by I. Fernström (1954). A catheter was inserted into the femoral artery on one side and both femoral arteries were compressed. The contrast medium was Umbradil 50 %, the same as that used in the phantom. 40 ml was injected within 2—3 seconds. Exposures 0.2 seconds with 150 mA at voltages varying from 105 to 110 kV. Cassettes with ordinary screens were used. The moving cross-grid, described in an earlier chapter, was used to obtain films *completely without grid structure*, a prerequisite for the densitometric studies. The films were developed in the ordinary roentgen film developer. Fig. 103 shows a film from a pelvic arteriography with the vessel phantom introduced into the vagina.

Selected films were analysed with a self-registering microdensitometer with a thermoelectric element and a galvanometer according to Moll. This apparatus was earlier used, for instance, by T. Caspersson

Fig. 103. A pelvic arteriograph made with a vessel phantom in the vagina. This contains channels, 0.6 and 1.0 mm in size, filled with Umbradil, 35 and 50 % respectively. The injection was made with a 50 % solution.

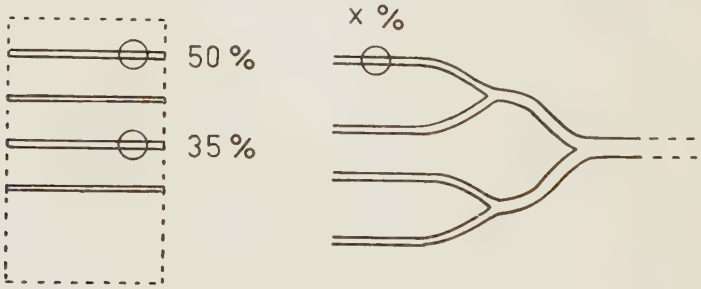


Fig. 104. The principle of the microdensitometric studies with vessel phantoms. To the left the phantom with contrast-filled channels, to the right the vessel branches. A microdensitometric comparison is made between lumina of equal size, for instance, those marked with circles.

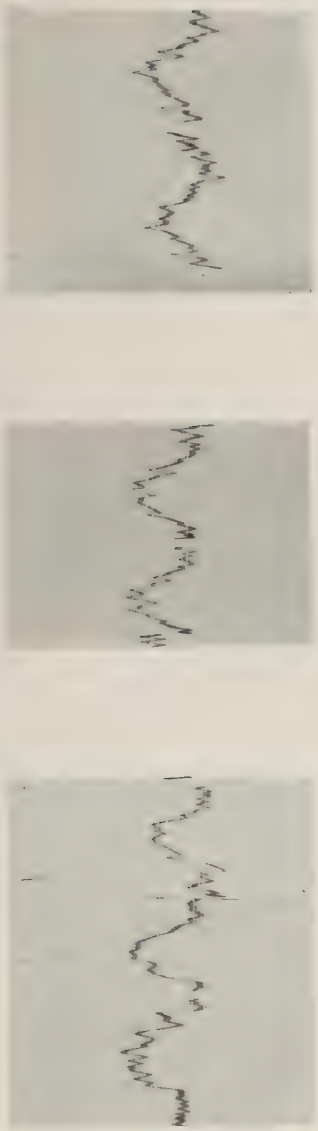


Fig. 105. Microdensitometric curves obtained with *35* % solution of Umbradil within the vessel phantom.

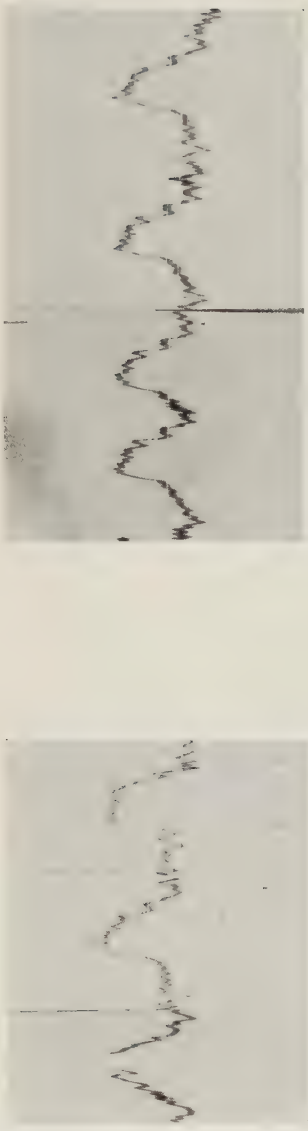


Fig. 106. Microdensitometric curves obtained with *50* % solution of Umbradil within the vessel phantom.

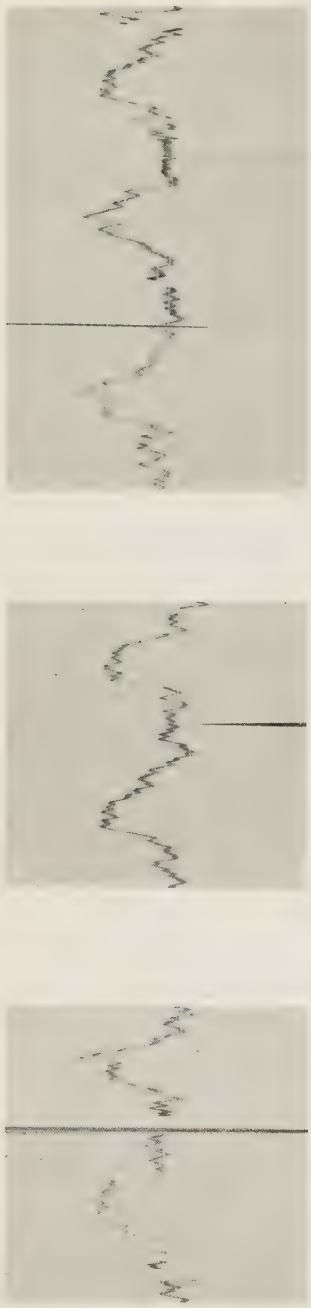


Fig. 107. Microdensitometric curves obtained with the contrast medium in the vessels during a pelvic arteriography. The diameter of the analysed column of contrast medium is the same a sin Figs. 105 and 106 (= 1.0 mm).

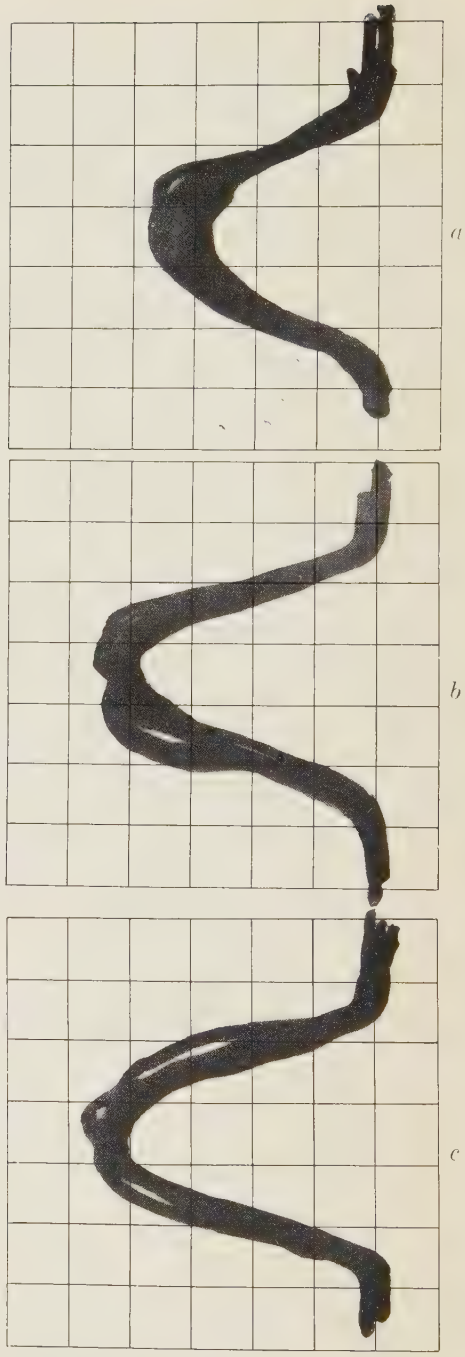


Fig. 108 *a—c*. Curves superimposed in a photographical way representing the mean value of the microdensitometric recordings shown in Figs. 105, 106, and 107, respectively. Note the similarity between *b* and *c*.

(1936), for determining the absorption of different cellular structures from microphotographs made with ultraviolet light. From different regions of the films, according to the principle shown in Fig. 104, densitometric curves were produced representing the variation of density along a line perpendicular to the recorded vessels. The channels of the test objects of known size and concentration, as well as vessel branches of the same size were studied. Many densitometric curves were made of the latter and those showing the lowest density were selected for the comparison. It could then be expected that the vessels concerned had been depicted with an approximately perpendicular direction of rays similarly to the test object. All studies were made within regions with exactly the same film density of the background. The electrical supply of the source of light in the densitometer was maintained constant.

Densitometric curves from one of the test series are shown in Figs. 105 to 107 on pp. 191 and 192. Fig. 105 corresponds to the recordings of the 35 % solution of the contrast medium and Fig. 106 to the 50 % solution, both within the phantom, the channels being 1.0 mm in diameter. Fig. 107 refers to the recordings of vessels of corresponding size. The curves are shown in natural size. The error that may be caused by the fact that the contrast medium in the channels is surrounded by the casting material, which is not of a true soft tissue character, may be considered to be of a very small order.

The curves were treated in a special manner in order to make an adequate comparison possible. They were magnified photographically six times. In this operation precautions were taken to keep their relative dimensions unchanged, a factor which is of importance since the film base and the paper base ordinarily show a considerable shrinkage during processing. Such problems have been briefly discussed by the writer (1951). In order to obtain a levelling of the unavoidable irregularities in the curves, caused by graininess of the photographic layer, etc., a levelled curve was drawn for each of them. The area bounded by such a smooth curve should represent an equivalence to that bounded by the original curve. By photographic means a superimposition of these levelled curves was produced and the results are shown in Fig. 108 *a*—*c*.

There is a striking similarity between the curves with the 50 % solution of contrast medium inside the phantom (*b*) and those with contrast medium in vessels of corresponding diameter (*c*), while the curves with the 35 % contrast solution have quite different configurations. From these observations the conclusions may be drawn that in these tests during the short moment of exposure, the contrast medium in the vessels has been practically undiluted. This fact is of a certain interest since it corresponds to opinions presented by S. R. Kjellberg (1943) and T. Greitz (1954). In connection with other angiographic

specialities and on the basis of experiments these authors emphasized that the contrast media are disinclined to mix with the blood. The rapid injection will probably produce a column of undiluted solution which will be divided into smaller parts in the vessel branches. The effect of sedimentation cannot be neglected and, naturally, all vessels will not be filled with undiluted solutions. The posture of the patient and other factors will be of importance.

In connection with pelvic arteriographies the smallest-sized contrast-filled channel, which could be discerned on the films was also studied. The blocks containing a series of channels of decreasing dimensions filled with Umbradil 50 % were then used. Cf. Fig. 102. On films exposed in an ordinary manner with a moving cross-grid all dimensions down to 0.3 mm could be interpreted in almost all cases. Channels of the dimension 0.2 mm were never seen. 0.25 mm channels, which were also tried, could only rarely be discerned. Although this series of tests is fairly limited, it is of a certain interest in that it shows that, with the technique and conditions of examination described, vessels down to a size of about *0.3 mm* may be made visible. It should be pointed out that Å. Lindbom (1950) in discussing peripheral vessels, which present less complicated radiographic problems, has quoted the same dimension.

SUMMARY

In the general survey of the high-voltage technique the progress made since the first attempts to use voltages up to 100 kV, in about 1924, is reported. The various benefits of higher voltages in medical radiography are discussed on the basis of the experiences of several authors. The gain in photographic effect, the possibilities of using extremely small focal dimensions, which paved the way for new applications, and some important physical problems are discussed. The lower differentiation of tissue opacities which gives the radiograph a new character, as well as the increased importance of secondary scatter which calls for secondary diaphragms of a more intricate construction, are also touched upon in the first introductory section.

A series of my own investigations illustrate, by means of graphs, some of the most important factors concerning radiography at higher voltages. They were made with a constant potential circuit up to 180 kV, and in conditions similar to those of ordinary radiography. The exposure required for unit film density with screen-film combination and non-screen film showed a very marked reduction with increasing voltage, which was especially obvious with the former material. A further analysis of the problem shows that this reduction will be explained, firstly by higher radiation output of the tube, and secondly by higher penetration of the object. These factors are illustrated by graphs. Thirdly, the sensitivity of the photographic material, screen-film combination and non-screen film, respectively, plays an important part. The former shows a steady increase in sensitivity to radiation of higher energies, but the latter a moderate reduction. The conditions of dosage are illustrated by graphs which show that the reduction of dose is not really quite so distinct, as the general opinion will have it. The effect of additional tube filtration upon dose and exposure is also shown.

The change in contrast with the voltage of certain substances is reported on the basis of photographic tests. These include salts of iodine, barium and calcium as well as water and paraffin, which represent soft tissues and body fat, respectively. The reduction of the photographic effect of the radiation in passing through the substances is shown graphically. Heavy substances, containing barium and iodine, show a marked change of their effect upon the radiation with raising voltage, but the light substances only a slight one. Calcium salts stand apart, showing an extremely high change. The recording of the contrasts depends on

the character of the photographic material in question, and there is a difference in result between films with screens and non-screen films. The latter which are less sensitive to harder rays, were found to record the contrasts better, since the filtering action of, for instance, the heavier substances gives a harder radiation.

The influence of processing upon the photographic recording of contrasts is reported. The importance of the gamma value and the shape of the density curve are discussed on the basis of tests. The shape of the density curve does not change with variations of voltage, but its location in the graphical system will change as the radiation sensitivity varies. The importance of correct development is pointed out, and ways of obtaining constant development with high contrast throughout long periods in everyday routine is discussed. The need of adequate replenishing is emphasized.

A retrospective survey of the screen problem is given as a background for a discussion of a new type of screen for medical radiography at higher voltages, containing barium lead sulphate as the fluorescent substance. Practical tests show the relative exposure required with these screens as compared with ordinary calcium tungstate screens. The definition is studied by comparative tests. The new screens are superior as regards speed, with an optimum at 110—120 kV, but give a much lower definition, which makes their value debatable. Certain properties of other screens are also discussed, and a brief comment on metal screens is made. In medical radiography lead screens seem to be of no value for intensifying purposes, at least in the region up to 180 kV.

Cross-grids, which, in connection with high-voltage technique, represent a superior solution of the problem of secondary diaphragming, have practically always been used without motion. Elimination of visible grid pattern in the film by proper motion is a main topic of the chapter on cross-grids, grid motion and visible pattern. A review is first presented of the evolution of secondary screening with special reference to the rôle of the cross-grid principle. The absence of information concerning the adequate motion of a cross-grid for homogeneous illumination of the film is pointed out. On the basis of photographic experiments a geometrical analysis is made of the distribution of illumination behind a moving grid. The suitable directions of motion of the crossed grid system for homogeneous illumination are defined, and applications to systems of different types discussed. Models of grid mechanisms made along the lines deduced have been used in practical work for angiographic examinations, etc. and have proved to give films completely free from any visible pattern.

The detrimental effect of a superimposed pattern on the definition of fine details is discussed, and special tests with a phantom of Schober's design are reported, which reveal a marked increase in the rendering of

details with the grid in motion. Some technical problems connected with the motion are also analysed.

A cause of irregular illumination of the film behind a moving grid is stroboscopy, explained by intermittence in current supply. The possibilities of stroboscopic pattern appearing in the film with different speeds are analysed. The importance of a constant and selectively chosen speed for preventing stroboscopic effects is pointed out.

A brief review is given of applied principles of motion of some modern grid mechanisms. The connection between the type of motion and the freedom from pattern obtained is discussed. A construction of a grid mechanism suited for modern demands is outlined.

Off-focus radiation and backscatter are among the factors which influence the quality of the radiographic image. A brief survey of the literature on off-focus radiation is given, and a study of modern tubes is made with a pin-hole camera. The principal source of off-focus rays is shown to be in the focal plate. The incomplete elimination of off-focus radiation by ordinary primary diaphragms is pointed out, and the importance of the close-to-focus principle is demonstrated. A study of the size of off-focus radiation in ordinary radiography is reported, and some practical aspects are presented, which emphasize that the diaphragm should be situated close to the tube window.

The backscatter phenomenon, which has not been much discussed in connection with radiography, is by no means without importance. Experiments presented show its effect in radiography with and without screens. Some simple methods for optimal reduction of its effect are discussed. The introduction of thin sheets of iron will prove very favourable. Some related problems of importance for film changers are also commented upon.

Adequate studies of the possibilities of radiographic recording of certain objects are most easily made with phantoms. As yet no phantom has been available as a substitute for contrast-filled vessels. A series of attempts to make a vessel phantom resulted in a type which is described and which was used for experiments. Small channels cast within blocks of stearic acid were filled with, for instance, angiographic contrast media and could represent vessels. A microdensitometric comparison was made between the recordings of contrast-filled channels and vessels of similar size in connection with pelvic angiography, in which the vessel phantom was introduced into the vagina. These investigations, made possible by the use of moving cross-grids, showed that the contrast media will mostly not be subject to any dilution. This will probably be valid also for other examinations. The dimension of the smallest vessel that can be observed in the film is finally discussed.

REFERENCES

de Abreu, M.: Theory of simultaneous tomography. Am. J. Roentg. 60 (1948), 668.

Åkerlund, Å.: Die spiralförmige Sekundärblende. Acta radiol. 2 (1923), 77.

— Der »Spiralblendenkompressor», Spezialapparat für Detailbilder bei Kontrastuntersuchungen. Acta radiol. 10 (1929), 421.

Albers-Schönberg, H.: Die Röntgentechnik. 2. Aufl. Lucas Gräfe & Sillem, Hamburg 1906.

Alberti, W.: Der Skopograph, eine elektromagnetisch gesteuerte Vorrichtung zur Herstellung gezielter Momentaufnahmen. Röntgenpraxis 2 (1930), 847.

Allen, E. P. and Calder, H. W.: Soft-tissue radiography. Brit. J. Radiol. 13 (1940), 422.

v. Allen, W. W. and Morgan, R. H.: Measurements of resolving power of intensifying screens. Radiology 47 (1946), 166.

Alvarez, W. C.: A note on use of Bucky Potter diaphragm with fluoroscope. Am. J. Roentg. 10 (1923), 69.

Axén, O.: Vergleich zwischen der Detailerkennbarkeit auf Schirmbildphotographien, bei der Durchleuchtung und auf Grossfilmaufnahmen. Acta radiol. 22 (1941), 547.

Backlund, V.: Simultaneous telefilm planigraphy. Acta radiol. 41 (1954), 425.

Báron, J.: Einfache Kontrolle der Nachleuchtungsfreiheit von Durchleuchtungsschirmen. Röntgenpraxis 4 (1932), 932.

Beck, A.: Technik der Tomographie mit directer Röntgenvergrösserung. Fortschr. Geb. Röntgenstr. 77 (1952), 611.

Bell, G. E.: The photographic action of X-rays. Brit. J. Radiol. 9 (1936), 578.

Biermann, A. and Boldingk, W. H.: The relation between tension and exposure times in radiography. Acta radiol. 35 (1951), 22.

Bloch, M. F.: Der sichtbare Blendenraster bei Röntgenaufnahmen unter Verwendung von Bucky-Rollblenden und seine Ursachen. Agfa Röntgenblätter 3 (1933), 33.

Boldingk, H.: Ein Verfahren zur Prüfung des Entwicklers. Acta radiol. 11 (1930), 217.

Bouwers, A.: Self-protecting tubes and their influence on the development of X-ray technique. Radiology 13 (1929), 191.

— An X-ray tube with rotating anode. Physica 10 (1930), 125.

— and v. d. Tuuk, J. H.: Secondary electrons in X-ray tubes. Physica 12 (1932), 274.

Bronkhorst, W.: Kontrast und Schärfe im Röntgenbilde. G. Thieme Verlag, Leipzig 1927.

Buchheim, E.: Grundlagen und Ergebnisse der Hartstrahltechnik. Dissertation, Erlangen 1952.

Büchner, H.: Direkter Röntgenvergrösserung und normale Aufnahme. Fortschr. Geb. Röntgenstr. 80 (1954), 71.

Bücker, J.: Erfahrungen mit der Hartstrahltechnik und der Feinstfokusröhre. Fortschr. Geb. Röntgenstr. 77 (1952), 153.

Buckstein, J.: Spot film fluororoentgenography with movable grid. Am. J. Roentg. 53 (1945), 608.

Bucky, G.: Über ein neues Blendenverfahren bei Röntgendurchleuchtungen. Med. Klinik 43 (1912), 1745.
— Über die Ausschaltung der im Objekt entstehende Sekundärstrahlen bei Röntgenaufnahmen. Verhandl. d. Deutschen Röntgen-Gesellsch. 9 (1913), 30.
— Methods of and apparatus for projecting Röntgen images. U. S. P. 1,164,987. Dec. 21, 1915.
— Vorrichtung zur Vermeidung der bildverschleiernden Wirkung der Sekundärstrahlen bei der Herstellung von Röntgenbildern. D. R. P. 411,675. Oct. 11, 1922.
— Vorrichtung zur Vermeidung der bildverschleiernden Wirkung der Sekundärstrahlen bei der Herstellung von Röntgenbildern. Zusatz zum Patent 411,675. Nov. 16, 1922.
Burger, G. C. E. and v. Dijk, D.: Zur Bestimmung der kleinst wahrnehmbaren Objektgrösse bei der Durchleuchtung. Fortschr. Geb. Röntgenstr. 58 (1938), 382.
Caldwell, E. (1916) quoted by Å. Åkerlund (1923).
Camp, J. D.: A grid-front cassette; a useful application of stationary grid. Radiology 49 (1947), 627.
Caspersson, T.: Über den chemischen Aufbau der Strukturen des Zellkernes. Skand. Arch. f. Physiol. Suppl. 73 (1936).
Cassen, B. and Corrigan, K. E.: Note on the reduction of backscatter from roentgen beams. Am. J. Roentg. 40 (1938), 608.
Chamberlain, W. E. and Newell, R. R.: Method of determining potency of developers. Am. J. Roentg. 23 (1930), 549.
Chantraine, H.: Hartstrahl- oder Weichstrahlverfahren bei Lungenaufnahmen. Fortschr. Geb. Röntgenstr. 33 (1925), 723.
— Über einen neuen scharf zeichnenden Verstärkungsschirm. Röntgenpraxis 4 (1932), 568.
— Von grossen und kleinen Röntgenmaschinen, von weichen und harten Strahlen. Röntgenpraxis 5 (1933), 659.
— Über die Unschärfe des Verstärkungsschirmes. Fortschr. Geb. Röntgenstr. 48 (1933), 613.
— Über ausreichende Beleuchtung, ausreichende Entwicklung und ausreichend helle Betrachtungskästen. Fortschr. Geb. Röntgenstr. 48 (1933), 346.
— Vorrichtung zur Verhinderung der Rasterbildung bei der Herstellung von Röntgenaufnahmen. D. R. P. 17. August 1938.
— Die völlige Beseitigung der Streustrahlen bei Röntgenaufnahmen. Röntgenpraxis 11 (1939), 37.
— and Walther, B.: Zur Frage der hellen und dunkeln Linien in einfachen medizinischen Röntgenaufnahmen. Fortschr. Geb. Röntgenstr. 46 (1932), 710.
Clark, K. C.: An introduction to high voltage technique. Radiography 19 (1953), 21.
— Personal communication 1953.
— Cordiner, G. R. M. and Ellman, P.: Experiments in X-ray screen photography with control direct radiographs. Brit. J. Radiol. 14 (1941), 54.
Clerc, L. P.: Photography. Theory and Practice. 2. Ed. Sir Isaac Pitman & Sons, Ltd. London 1947.
Cocchi, U.: Die Hartstrahltechnik in der Röntgendiagnostik. Fortschr. Geb. Röntgenstr. 81 (1954), 24.
— Die Röntgenuntersuchung des Verdauungstraktus sowie der Gallen- und Harnwege mittels Hartstrahltechnik. Acta radiol. Suppl. 116 (1954), 561. The invited papers of the Seventh International Congress of Radiology.
Cohn, M. und Barth, W.: Die stereoskopische Lokalisation. Lehrbuch der Röntgenstereoskopie. G. Thieme Verlag, Leipzig 1931.
Cole, L. G. quoted by R. B. Wilsey (1921).

Cole, P. F.: New application of flat Bucky grid to any angle with special reference to sinus work. Radiology 20 (1933), 1.
Compton, A. H.: The scattering of X-rays. Radiology 3 (1924), 479.
Coolidge, W. D.: Röntgenröhre mit reiner Elektronentladung. (Auszug aus einer Abhandlung in der Phys. Review Dec. 1913.) Fortschr. Geb. Röntgenstr. 22 (1914), 18.
Corrigan, K. E.: Physical factors influencing the difference between 200 and 500 kV radiation. Radiology 34 (1940), 8.
Craeybeckx, A. H. S.: Manuel de photographie Gevaert. Dixième édition. Photo-produits Gevaert S. A. Mortsel (Anvers), Belgique 1949.
Dehio, H.: Gleichmässiger Kontrast bei der Röntgenentwicklung. Fortschr. Geb. Röntgenstr. 58 (1938), 507.
v. Dijk, D.: Obtaining the best results in radiography. Philips Metalix Bulletin 1 (1951).
Diserens, C.: Handbuch der Photographie. Band II. Photographische Chemie. Verlag Hallwag Bern.
Distel, H.: Detailwiedergabe, Reflexlicht- und Kontrast im Schirmbild. Fortschr. Geb. Röntgenstr. 71 (1949), 134.
Eberhard, W.: Die Feinrasterkassette. Röntgenpraxis 14 (1942), 112.
Eggert, J.: Einführung in die Röntgenphotographie. 7. Auflage. S. Hirzel Verlag, Zürich 1951.
Facci, F.: Sopra una causa poco nota determinante la impronta della griglia nelle radiografie rapide eseguite mediante antidiffusore. Quaderni radiol. 6 (1935), 254.
Fernström, I.: Personal communication 1954.
— Arteriography of the uterine artery. Acta radiol. Suppl. under printing.
Files, G. W.: The relation, radiographically, of kilovolts peak to time of exposure. Radiology 7 (1926), 255.
Finzi, N. S.: A new intensifying screen. Brit. J. Radiol. 6 (1933), 103.
Flarsheim, E. F. (1931) quoted by H. Potter (1931).
Franke, H.: Influence des écrans renforçateurs sur le contraste des images radiologiques. Arch. d'électr. méd. 40 (1932), 35.
— Streuung und Superposition als zerstörende und aufbauende Elemente der Bildgebung. Fortschr. Geb. Röntgenstr. 64 (1941), 288.
Fransen, J. and Oosterkamp, W. J.: A universal roentgen dosemeter. Transactions of the Instruments and Measurements Conference, Stockholm 1952.
Frantzell, A.: The practical roentgenographic importance of reciprocity law failure. Acta radiol. 34 (1950), 6.
— Soft tissue radiography. Acta radiol. Suppl. 85 (1951).
— Effect of focal size, shape and »structure» on the roentgenographic representation of small-calibre metal objects. Acta radiol. 35 (1951), 265.
— Personal communication 1954.
Fray, W. W. and Hill, W. T.: A study of the changes in definition occurring with Bucky diaphragm of mobile type; new device for correcting chief effect resulting from its mobile character. Radiology 20 (1933), 456.
Frommhold, W.: Messungen über die Helligkeit von Verstärkerfolien. Röntgenblätter 7 (1954), 33.
Gajewski, H.: Die Grundlagen und Anwendungsmöglichkeiten der Hartstrahltechnik. Röntgenblätter 6 (1953), 53.
— Physikalische und aufnahmetechnische Gesichtspunkte bei Röntgenaufnahmen mit hohen Spannungen. Fortschr. Geb. Röntgenstr. 80 (1954), 643.
Glasser, O., Quimby, E. H., Taylor, L. S. and Weatherwax, J. L.: Physical foundations of radiology. 2. Ed. P. B. Hoeber, Inc. New York 1952.
Gortan, M.: Zur Technik der Moment- und Schnellaufnahmen. Verhandl. d. Deutschen Röntgen-Gesellsch. 15 (1924), 13.

Greitz, T.: The technique of ascending phlebography of the lower extremity. Acta radiol. 42 (1954), 421.
Groedel, F.: Die Lungen-Fern und Abstandsaufnahme. Fortschr. Geb. Röntgenstr. 33 (1925), 99.
Hansleuter, K.: Über die Verstärkerwirkung neuerer Kurzzeitfolien. Fortschr. Geb. Röntgenstr. 71 (1949), 1002.
Hartmann, J. H.: Verstärkerfolien, ihre Beurteilung und Eigenschaften. Fortschr. Geb. Röntgenstr. 43 (1931), 758.
Hasselwander, A.: Die objektive Stereoskopie an Röntgenbildern. G. Thieme Verlag, Stuttgart 1954.
Hawley, S. J.: Increased filtration for diagnostic purposes. Radiology 40 (1943), 387.
Herdner, R.: Au sujet des Potter-Bucky comment les déclencher automatiquement à distance. J. de radiol. et d'électrol. 11 (1927), 383.
— Noveau déclencheur pour antidiffuseur. J. de radiol. et d'électrol. 12 (1928), 508.
Herz, R. und Luft, F.: Untersuchung über die photographische Behandlung von Röntgenfilmen. Röntgenpraxis 5 (1933), 520.
Heuser, G. und Lemcke, W.: Über die Anwendung der direkten radiologischen Vergrösserungstechnik bei der Karotisarteriographie. Fortschr. Geb. Röntgenstr. 79 (1953), 239.
Hodges, P. C.: Automatic operation of Potter grid. Am. J. Roentg. 10 (1923), 645.
— A focal spot camera. Am. J. Roentg. 31 (1934), 399.
Ilford Manual of Photography. Edited by J. Mitchell. Published by Ilford Limited, Ilford, London, and H. Greenwood & Co. Ltd. London 1954.
Imbert, R.: Les filtres antidiffuseurs. J. de radiol. et d'électrol. 17 (1933), 233.
James, T. H. and Higgins, G. C.: Fundamentals of photographic theory. J. Wiley & Sons, Inc., New York. Chapman & Hall, Ltd. London 1949.
Jones, H. E.: The physic of radiation therapy. Charles C. Thomas Publ. Springfield, Illinois, U. S. A. 1953.
Jones, L. A.: Photographic sensitometry. Eastman Kodak Co., Rochester, N. Y. 1934.
Juris, K. and Rudinger, G.: Ein objektives Verfahren zur Prüfung der Zeichenschärfe von Verstärkungsfolien ohne Microphotometer und ein Schärfemessapparat. Fortschr. Geb. Röntgenstr. 56 (1937), 548.
— — Zur Frage der Körnigkeit von mit Verstärkerfolien hergestellte Röntgenaufnahmen. Fortschr. Geb. Röntgenstr. 57 (1938), 53.
Kemp, F. H.: A clinical evaluation of high voltage radiography in obstetrics and diseases of the chest. Acta radiol. Suppl. 116 (1954), 570. The invited papers of the Seventh International Congress of Radiology.
Kenny, J. M., Harvey, E. A., Woolsey, P. D. and Baines, H.: Exhaustion of developer and a practical method of periodic regeneration. Radiography 3 (1937), 115.
Keuser, A.: Eine einfache Aufnahme-Buckyblende. Röntgenpraxis 4 (1932), 1046.
Kjellberg, S. R.: Die Mischungs- und Strömungsverhältnisse von Wasserlöslichen Kontrastmittels bei Gefäss- und Herzuntersuchungen. Acta radiol. 24 (1943), 433.
— Personal communication 1950.
— A circulation system for keeping the developer constant. Acta radiol. 42 (1954), 296.
Klug, H.: Vergleichende Untersuchung an Verstärkungsfolien und Leuchtschirmen. Fortschr. Geb. Röntgenstr. 52 (Kongr.-H. 1935).
— Vergleichende Untersuchung der gebräuchlichen Durchleuchtungsschirme und Verstärkungsfolien. Fortschr. Geb. Röntgenstr. 55 (1937), 191.
Kodak Data Book of applied photography. Volume 2. Kodak Limited, London 1952.
Kodak Reference Book. Eastman Kodak Co. Rochester 4, N. Y. 1946.
Kroon, J.: Modern Reproduktion. (Swedish.) AB Malmö grafiska anstalt och AB Malmö ljustrycksanstalt, Malmö 1935.

Lamerton, L. F.: Physical investigations with 140 KVP radiation. Brit. J. Radiol. 14 (1941), 199.
Laurell, H.: Eine Methode beim Röntgenphotographieren den grösseren Teil des schädliches Sekundärstrahlung auszuschalten. Acta radiol. 12 (1931), 574.
— Metallfolien und Metalltücher als Sekundärblenden. Upsala Läkarfören. Förhandl. 37 (1931—1932), 439.
— Dünne Bleifolien als Sekundärblenden. Acta radiol. 13 (1932), 193.
Ledin, S.: Personal communication 1950, 1952, and 1954.
— The physical background of contrast in roentgenograms with special regard to scattered radiation. Stockholm 1952.
Leonard, R. D. and Georg, A. W.: Cassette with convex curve. Am. J. Roentg. 28 (1932), 261.
Lewin, H.: Beobachtungen an Sekundärstrahlblenden. Fortschr. Geb. Röntgenstr. 36 (1927), 1208.
Levy, L. and West, D. W.: New and much more rapid intensifying screen allowing great alterations in technic. Brit. J. Radiol. 6 (1933), 85.
— — Edgerton, H. A. and Brock, R. B.: Elimination of afterglow and latent phosphorescens from fluorazure intensifying screens. Brit. J. Radiol. 7 (1934), 344.
— — Ecrans modernes pour rayon X. J. de radiol. et d'électrol. 31 (1950), 466.
Lindblom, K.: Secondary screening by means of filtering. Acta radiol. 15 (1934), 620.
— On roentgenography at 200 kV. Acta radiol. 36 (1951), 162.
— On microtomography. Acta radiol. 42 (1954), 465.
Lindbom, Å.: Arteriosclerosis and arterial thrombosis in the lower limb. Acta radiol. Suppl. 80, 1950.
Lindell, B.: Secondary roentgen radiation. Acta radiol. 41 (1954), 353.
Lindemann, B.: Simultane Angiocardio-Tomographie. Fortschr. Geb. Röntgenstr. 73 (1950), 261.
Lindsay, H.: Signal light for Bucky-Potter diaphragms. Am. J. Roentg. 9 (1922), 67.
Longmore, T. A.: Medical photography, radiographic and clinical. Fourth Edition. The Focal Press, London and New York 1949.
Lorentzon, L.: Secondary roentgen radiation from wax, Al, Fe, and Pb at tube voltages between 40 and 170 kV. Acta radiol. 41 (1954), 201.
Lotzin, A.: Ein Verfahren zur Ausschaltung der sekundären Körperstrahlen bei Röntgenaufnahmen. Fortschr. Geb. Röntgenstr. 25 (1917—1918), 326.
Luckiesh, M.: Light, vision and seeing. D. van Nostrand Comp., Inc. New York 1945.
Lundh, A.: Personal communication 1954.
Mallet, L. and Maurin, R.: A study of quality and origin of parasitic radiation from the target of an X-ray tube. Radiology 48 (1947), 628.
Martin, F. C., Smith, E. E. and Hodgson, M. B.: A new system of standardized development. X-ray Bull. & Clin. Photography. Eastman Kodak Co. 5 (1929), 6.
Mattsson, O.: A simple masking method for the levelling of contrast in radiographic printing. Acta radiol. 35 (1951), 179.
— Automatic counting of radiographs: an aid in processing control. Acta radiol. 38 (1952), 215.
— A simple method of ensuring correct concentration of barium contrast media. Acta radiol. 39 (1953), 501.
Mees, C. E. K.: The theory of the photographic process. The Macmillan Company, New York 1952.
Meiler, J.: Die in der Röntgendiagnostik verwendeten Spannungskurvenformen und ihr Einfluss auf Bildqualität und Röhrenbelastung. Fortschr. Geb. Röntgenstr. 72 (1949, 1950), 222.

Moon, R. J.: Amplification and intensifying the fluoroscopic image by means of a scanning X-ray tube. Science 112 (1950), 389.
Morgan, R. H.: Reciprocity law failure. Radiology 42 (1944), 471.
— An analysis of the physical factors controlling the diagnostic quality of roentgen images. Am. J. Roentg. 54 (1945), 128. 54 (1945), 395. 55 (1946), 67. 62 (1949), 870.
— Characteristics of X-ray films and screens. Radiology 49 (1947), 90.
— and v. Allen, W. W.: The sensitometry of roentgenographic films and screens. Radiology 52 (1949), 832.
Müller, E. A. W.: Röhren-Gleichgerichterschaltungen und ihre Wirkungsweise. Archiv für Technisches Messen 171 (1950).
Neblette, C. B.: Photography, its principles and practice. 4. Ed. D. van Nostrand Company, Inc. New York 1947.
Neboschew, A. F.: Der Durchgriff als Kennwert der Röntgenröhren. Fortschr. Geb. Röntgenstr. 76 (1952), 102.
Nelson, A.: Determination of physical factors influencing the quality of the radiographic image. Acta radiol. Suppl. 76 (1949).
Nemet, A., Cox, W. F. and Hills, T. H.: The contrast problem in high kilovoltage medical radiography. Brit. J. Radiol. 26 (1953), 185.
— Personal communication 1953.
Norman, O.: Personal communication 1950 and 1953.
Olsson, O.: Easily sterilizable, flexible cassette with intensifying screens, designed for X-ray examination of operatively exposed kidneys. J. Urol. 61 (1949), 1032.
Oosterkamp, W. J.: Methoden zur Bekämpfung der Streustrahlen im diagnostischen Röntgenbild. Philips' Technische Rundschau 8 (1946), 183.
Ortmann and Wolf, P. M.: Beobachtungen über phosphoreszierende Erscheinungen am Röntgenschirm. Röntgenpraxis 10 (1938), 327.
Otto, W. (1914) quoted by Å. Åkerlund (1923).
Pape, R.: Über eigenartige Streifenschatten in gezielten Röntgenaufnahmen. Röntgenpraxis 6 (1934), 361.
Pasche, O.: Über eine neue Blendenvorrichtung in der Röntgentechnik. Fortschr. Geb. Röntgenstr. 6 (1903), 210.
Peltasson, F.: Zur Frage der Schärfenzeichnung bei Röntgenaufnahmen mit Verstärkungsfolie. Fortschr. Geb. Röntgenstr. 34 (1926), 691.
v. d. Plaats, G. J.: Prinzipen, Technik und medizinische Anwendung der radiologischen Vergrösserungstechnik. Fortschr. Geb. Röntgenstr. 77 (1952), 605.
v. d. Plaats, G. J., v. Dijk, D. and Coolsma (1941) quoted by Biermann and Boldingk (1951).
Pohl, E.: Röntgenröhre, insbesondere für Durchleuchtung und Aufnahme, mit von der Kathode umgebener Kegelanode. D. R. P. 662,408. 12. Mai 1934.
Potter, H.: Diaphragming roentgen rays. Studies and experiments. Am. J. Roentg. 3 (1916), 142.
— The Bucky diaphragm adapted to fluoroscopy. Am. J. Roentg. 4 (1917), 47.
— The Bucky diaphragm principle applied to roentgenography. Am. J. Roentg. 7 (1920), 292.
— The Bucky diaphragm principle applied to radiography of the spine. Am. J. Roentg. 8 (1921), 61.
— Principles underlying grid diaphragm, which limits its form and efficiency. Am. J. Roentg. 25 (1931), 528.
— Analysis of the flat grid and some less excentric forms. Am .J. Roentg. 25 (1931), 677.
— The grid diaphragm principle applied to roentgenography of paranasal sinuses. Am. J. Roentg. 25 (1931), 814.

Potter, H.: The grid diaphragm principle applied to stereographic study of mastoids. Am. J. Roentg. 26 (1931), 107.

Powell, E. W.: An automatic switch for Bucky diaphragms. Am. J. Roentg. 10 (1923), 67.

Profitlich, P.: Die Abhängigkeit des mA-Sek. Produktes von Filter und Spannung. Fortschr. Geb. Röntgenstr. 42 (1930), 252.

Quimby, E. H., Lucas, C. D., Arneson, A. N. and Mac Comb, W. S.: A study of backscatter for several qualities of roentgen rays. Radiology 23 (1934), 743.

— Marinelli, L. D. and Farrow, J. H.: A study of backscatter. Am. J. Roentg. 39 (1938), 799.

Rein, H.: Physiologie des Menschen. 2. Aufl. J. Springer, Berlin 1938.

Renwick, F. F. and Tasker, H. S.: Improvements in or relating to fluorescent materials. B. P. 540,252. April 9, 1940.

Rövekamp, T.: Wert der Hartstrahltechnik in der Röntgendiagnostik und Grenzen ihrer Leistungsfähigkeit. Röntgenpraxis 3 (1931), 806.

Rump, W.: Messungen an Streustrahlblenden. Fortschr. Geb. Röntgenstr. 58 (1938), 262.

Samuel, E.: Macroradiography (enlargement technique) in the radiology of the ear, nose and throat. Brit. J. Radiol. 26 (1953), 558.

Sawford, H. S.: Flat diaphragm of spiral design in roentgenography. Am. J. Roentg. 10 (1923), 737.

— The rotating spiral in roentgenography. Am. J. Roentg. 12 (1924), 196.

Schober, H.: Über Phantomarbeiten. Bericht über den 33. Deutschen Röntgenkongress, Baden-Baden 1951.

— Personal communication 1954.

— und Klett, C.: Untersuchungen über die Zeichenschärfe von Verstärkerfolien. Röntgenblätter 6 (1953), 214.

Schoen, D.: Hartstrahltechnik und Feinfokusröhre in der Diagnostik des Kehlkopfes. Fortschr. Geb. Röntgenstr. 78 (1953), 170.

Schönander, G.: A study of secondary screening. Acta radiol. 22 (1941), 796.

Schumann, G.: Personal communication 1953.

Seemann, H. E. (1938) quoted by H. S. Tasker (1945).

— Spectral sensitivity of two commercial X-ray film between 0.2 and 2.5 Ångström. The Review of Scientific Instruments 21 (1950), 314.

Shearer, J. S.: The nature and origin of secondary radiation. Am. J. Roentg. 4 (1917), 50.

Smith, F. H.: Photographs and the printer. The Focal Press, London and New York 1948.

Soresi, A. L.: A new diaphragm for the complete elimination of secondary radiation. Radiology 16 (1931), 486.

Spencer, D. A.: Progress in Photography 1940—1950. The Focal Press, London and New York.

Spiegler, G.: Die Streustrahlung in ihrer Wirkung auf die Bildgebung. Fortschr. Geb. Röntgenstr. 51 (1935), 498.

— The story of contrast and definition. Radiography 16 (1950), 177.

— Das Röntgenbild — dosimetrisch betrachtet. Fortschr. Geb. Röntgenstr. 80 (1954), 754.

— and Rudinger, G.: Zum Wesen der Folienunschärfe. Fortschr. Geb. Röntgenstr. 57 (1938), 56.

Spiers, F. W.: Effective atomic number and energy absorption in tissues. Brit. J. Radiol. 19 (1946), 52.

Stanford, B.: The optimum combination of film and fluorescing screen. Brit. J. Radiol. 14 (1941), 128.
— Effect of varying the coating thickness of the fluorescing material of a screen on the luminous output obtained. Brit. J. Radiol. 14 (1941), 392.
Stephani, J.: De l'emploi de l'antidiffuseur pour les radiographies pulmonaires. J. de radiol. et d'électrol. 13 (1929), 393.
Steps, H.: Untersuchungen an Röntgenleuchtschirmen. Fortschr. Geb. Röntgenstr. 52 (1935), 293.
Swindells, F. E.: Some properties of intensifying screens. Am. J. Roentg. 17 (1927), 115.
— Physical properties of fluorescent screens. Radiology 11 (1928), 424.
— Effect on speed of intensifying screens. Radiology 14 (1930), 387.
Tasker, H. S.: Improvements in or relating to fluorescent materials. B. P. 540,253. April 9, 1940.
— Recent advances in industrial radiography. Phot. J. 85 A (1945), 95.
— Some properties and uses of X-ray intensifying screens. Phot. J. 85 B (1945), 75.
Tauleigne, J. B. et Mazo, G.: Sur l'élimination du rayonnement secondaire. Arch. d'électr. médicale 26 (1918), 160.
Thoraeus, R.: The amount of off-focus radiation in beams from various types of Roentgen tubes. Acta radiol. 18 (1937), 753.
Timmermanns, F.: Röntgenblende mit schräg verschobener Rasteranordnung. Pat. appl. 1936.
Trout, E. D., Kelley, J. P. and Cathey, G. A.: The use of filters to control radiation exposure to the patient in diagnostic radiology. Am. J. Roentg. 67 (1952), 946.
— — The experimental back-ground and current uses of high kilovoltage radiography. Acta radiol. Suppl. 116 (1954), 574. (The invited papers of the Seventh International Congress of Radiology.)
Trump, J. G. and Cloud, R. W.: Physical characteristics of supervoltage roentgen rays. Am. J. Roentg. 44 (1940), 615.
Tuddenham, W. J., Hale, J. and Pendergrass, E. P.: Supervoltage diagnostic Roentgenography, a preliminary report. Am. J. Roentg. 70 (1953), 759.
de Waard, R. H.: Der Nutzeffekt von Streustrahlblenden. Fortschr. Geb. Röntgenstr. 49 (1934), 415.
— Die Bedeutung der Selektivitet von Streustrahlenblenden für die Kontraste im Röntgenbild. Fortschr. Geb. Röntgenstr. 50 (1934), 606.
Wachsmann, F.: Dosisbelastung des Patienten bei diagnostischen Untersuchungen. Fortschr. Geb. Röntgenstr. 75 (1951), 728.
– Breuer, K. und Buchheim, E.: Grundlagen und Ergebnisse der Hartstrahltechnik. Fortschr. Geb. Röntgenstr. 76 (1952), 147.
Wagner: Beobachtungen über phosphoreszierende Erscheinungen am Röntgenschirm. Röntgenpraxis 10 (1938), 43.
Wahl, F. A.: Beitrag zur Verbesserung der Bildqualität in der Röntgentechnik. Röntgenpraxis 3 (1931), 855.
Vallebona, A.: Radiography with great enlargement (microradiography); technical method for dissociation of shadow. Radiology 17 (1931), 340.
Walstam, R.: Dose measurements on secondary roentgen radiation. Acta radiol. 41 (1954), 348.
Walther, B.: Über scheinbare Helligkeitsmaxima und -minima in einfachen Röntgenbildern. Fortschr. Geb. Röntgenstr. 25 (1917), 88.
Watkins, A. (1893) quoted by L. P. Clerc 1947.

Watson, W.: The making of diagnostic radiographs. II. With and without Potter-Bucky diaphragms. Radiography 2 (1936), 114.
— An oscillating grid. Radiography 11 (1945), 22.
— Simultaneous multisection radiography. In 'Modern trends in diagnostic radiology'. Butterworth & Co. London 1953.
Weber, E.: Über Aufnahmen mit harten Strahlen. Fortschr. Geb. Röntgenstr. 32 (1924), 585.
— und Brezina, O.: Experimentelle Bestimmung der zulässigen Verschiebung eines Objektes während des Exposition und eine Methode zur Bestimmung der notwendigen Expositionszeit und der Leistungsfähigkeit der Apparate und Röhren für eine Reihe von schwierigen röntgenographischen Aufgaben. Fortschr. Geb. Röntgenstr. 34 (1926), 543.
— und Russo, C.: Über die Abhängigkeit der Expositionszeit von der Spannung. Fortschr. Geb. Röntgenstr. 43 (1931), 226.
Wegelius, C.: Personal communication 1953.
— The diagnostic use of high voltage rays in relationship to the physical background of mass absorption. Acta radiol. Suppl. 116 (1954), 589. The invited papers of the Seventh International Congress of Radiology.
Williams, M.: Radiation from an oil-immersed therapy tube. Radiology 26 (1936), 749.
Williamson, G.: Personal communication 1953.
Wilsey, R. B.: The intensity of scattered X-rays in radiography. Am. J. Roentg. 8 (1921), 328.
— The effect of scattered radiation in radiography. Am. J. Roentg. 8 (1921), 589.
— The efficiency of Bucky diaphragm principle. Am. J. Roentg. 9 (1922), 58.
— Some practical results with a Potter-Bucky diaphragm. Am. J. Roentg. 9 (1922), 441.
— The measurement of intensifying factors of X-ray intensifying screens. Radiology 2 (1924), 311.
— The laws of development of X-ray films. Radiology 5 (1925), 237.
— Scattered radiation in roentgenography of the chest; preliminary report (use of Potter diaphragm). Radiology 23 (1934), 198.
— The use of photographic film for monitoring stray X-rays and gamma rays. Radiology 56 (1951), 229.
Wilson, C. W.: Quantity and quality of radiations scattered within medium irradiated by high voltage radiation. Brit. J. Radiol. 18 (1945), 344.
— Observations concerning secondary electronic emission from certain materials by means of its photographic action. Brit. J. Radiol. 23 (1950), 478.
Wood, E. H.: Preliminary observations regarding value of a very fine focus tube in Roentgen diagnosis. Radiology 61 (1953), 382.
Zacher, F.: Röntgenaufnahmen mit harter Strahlung. Fortschr. Geb. Röntgenstr. 33 (1925), 251.
Ziedses des Plantes, B. G.: Planigraphie. Fortschr. Geb. Röntgenstr. 47 (1933), 407.
Ziegler, J.: Eine neue Rotationsblende zur Abschirmung der Sekundärstrahlen. Fortschr. Geb. Röntgenstr. 31 (1923—1924), 450.
Zimmer, E. A.: Methodische Bemerkungen und Leitsätze zur direkten Röntgen-Vergrösserung. Fortschr. Geb. Röntgenstr. 75 (1951), 292.

Corrections

Page 18. Some physical problems, 15th line: dominates in harder radiation, owing to higher penetration, *should be:* increases with harder radiation.

Page 25. Experimental arrangements, 2nd line: tube-to-film distance, *should be:* focus-to-film distance.

Page 31. Legend for Fig. 7, *to be added:* Constant potential circuit.

Price Sw. Kr. 30:—